75th Congress, 2d Session · House Document No. 398

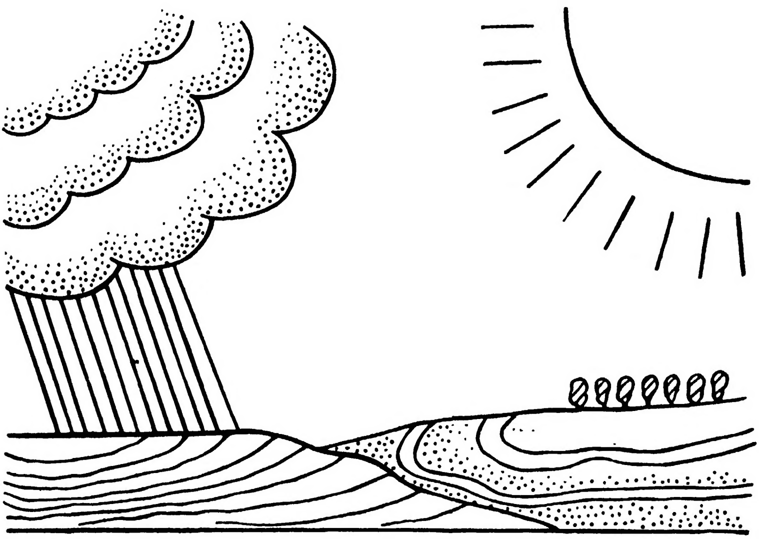
United States Department of Agriculture

YEARBOOK OF AGRICULTURE

1938

Soils & Men

Yearbook of Agriculture 1938



UNITED STATES DEPARTMENT OF AGRICULTURE

UNITED STATES GOVERNMENT PRINTING OFFICE

Organization

of the United States Department of Agriculture

Corrected to July 1, 1938

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Foreword

THE EARTH is the mother of us all—plants, animals, and men. The phosphorus and calcium of the earth build our skeletons and nervous systems. Everything else our bodies need except air and sun comes from the earth.

Nature treats the earth kindly. Man treats her harshly. He overplows the cropland, overgrazes the pastureland, and overcuts the timberland. He destroys millions of acres completely. He pours fertility year after year into the cities, which in turn pour what they do not use down the sewers into the rivers and the ocean. The flood problem insofar as it is man-made is chiefly the result of overplowing, overgrazing, and overcutting of timber.

This terribly destructive process is excusable in a young civilization. It is not excusable in the United States in the year 1938.

We know what can be done and we are beginning to do it. As individuals we are beginning to do the necessary things. As a nation, we are beginning to do them. The public is waking up, and just in time. In another 30 years it might have been too late.

The social lesson of soil waste is that no man has the right to destroy soil even if he does own it in fee simple. The soil requires a duty of man which we have been slow to recognize.

In this book the effort is made to discover man's debt and duty to the soil. The scientists examine the soil problem from every possible angle. This book must be reckoned with by all who would build a firm foundation for the future of the United States.

For my own part I do not feel that this book is the last word. But it is a start and a mighty good start in helping all those who truly love the soil to fight the good fight.

HENRY A. WALLACE, *Secretary of Agriculture.*

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In charge of Part I, The Nation and the Soil, Bushrod W. Allin; Part II, The Farmer and the Soil, A. L. Patrick; Part III, Soil and Plant Relationships, M. A. McCall; Part IV, Fundamentals of Soil Science, and Part V, Soils of the United States, Charles E. Kellogg.

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Part II. The Farmer and the Soil

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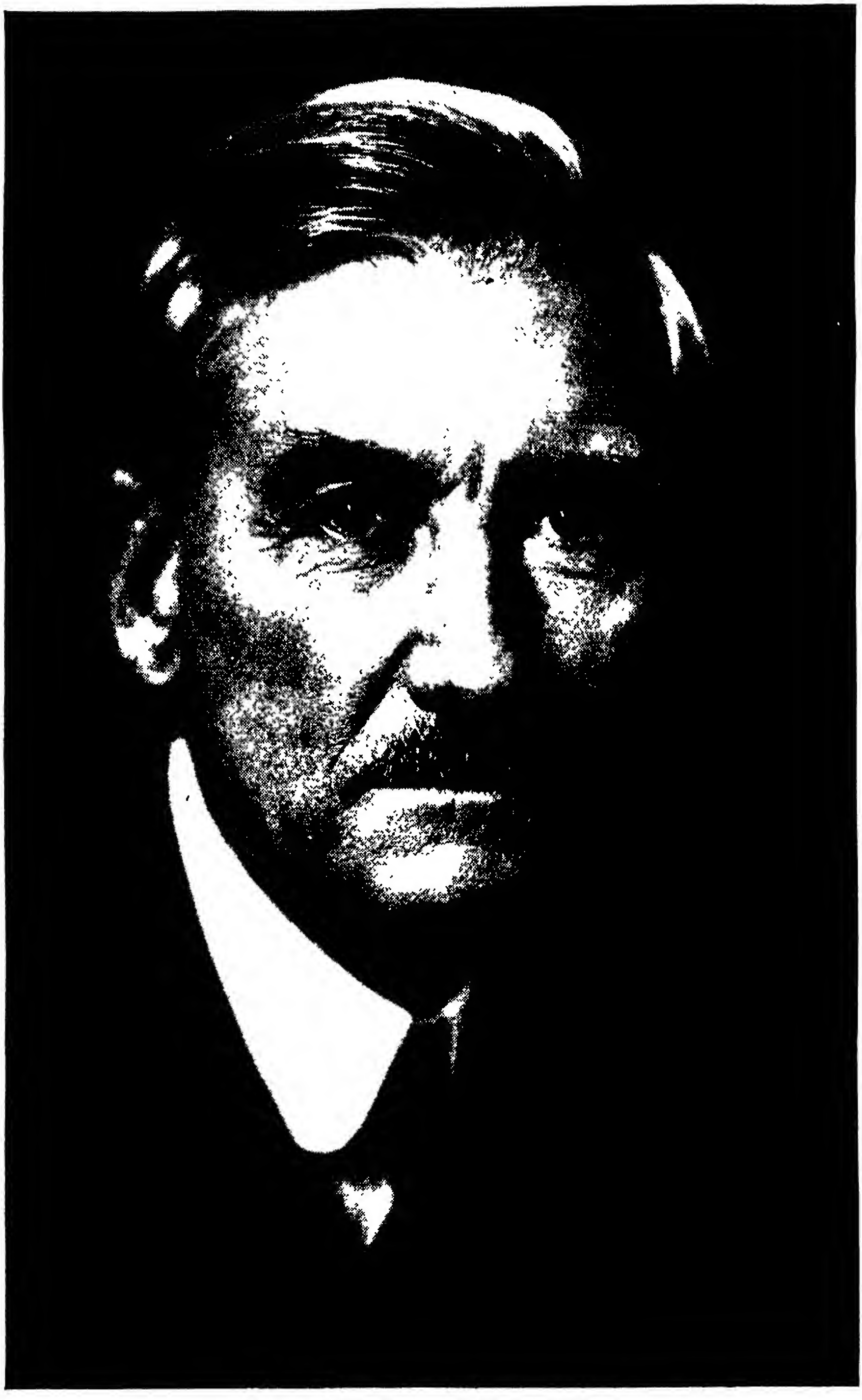
NOTE: The Annual Report of the Secretary of Agriculture to the President of the United States for 1937, hitherto printed in the Yearbook, has been omitted from this volume. It is published as a separate document and may be obtained from the Superintendent of Documents, Washington, D. C., at 15 cents a copy.



CURTIS FLETCHER MARBUT

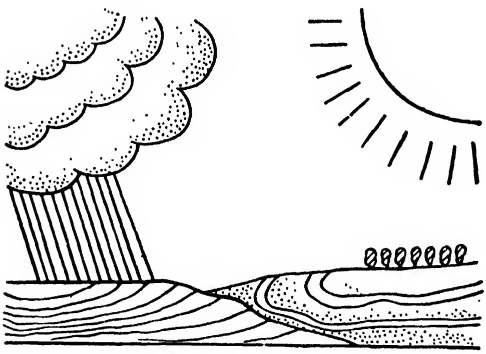
TO THE MEMORY OF

Curtis Fletcher Marbut

MR. MARBUT was for many years chief of the Soil Survey Division in the United States Department of Agriculture. Under his guidance, work in soils became a recognized science in the United States. His own researches in soil classification and geography laid the foundation for our modern concepts of soil. Although this work by itself is of the utmost significance, perhaps his greatest influence was exerted by more subtle means. No man better exemplified the scientific spirit. His devotion to truth and freedom from prejudice were coupled with a modest, kindly personality that inspired all his associates as well as young men everywhere who were interested in soil science. Although he became a citizen of the world, he retained the simple habits of his early life in the Missouri Ozarks. He died at Harbin, Manchuria, while on an expedition to China.

Soils & Men

A
Summary



Soils and Men—A Summary

By Gove Hambidge [1]

A CERTAIN MAN had a fine horse that was his pride and his wealth. One morning he got up early to go out to the stable, and he found it empty. The horse had been stolen. He stayed awake many nights after that thinking what a fool he had been not to put a good stout lock on the stable door. It would have cost only a couple of dollars and saved his most prized possession. He resolved that he would give better protection to the next horse he had, but he knew he would never get one as good as the one he had lost.

The United States has been like that about its soil. Within a comparatively short time, water and wind have flayed the skin off the unprotected earth, causing widespread destruction, and we have been forced to realize that this is the result of decades of neglect. The effort to relieve economic depression for farmers has also forced attention on the soil. In the old Roman Empire, all roads led to Rome. In agriculture all roads lead back to the soil, from which farmers make their livelihood.

The impact of recent events and viewpoints on agricultural institutions is very great. In the main, they have made for closer coordination and unification so that all may work effectively toward common objectives. What, broadly, are the objectives? They have been summed up briefly by the Director of the Office of Land Use Coordination as (1) greater stability and efficiency of farm production; (2) greater stability of natural resources—conservation of soil and its fertility; better control of floods; and conservation of forests, water, forage, and wildlife; (3) greater stability of farm prices and income, and a better rural-urban balance; (4) greater security of tenure—a higher percentage of farmers owning their own land and a better tenure system for those who continue as tenants; (5) higher standards of rural living, and stability of rural communities, governments, and regions. Merely to set down these objectives is to see at once that they cannot be achieved without concerted planning and action by

[1] Gove Hambidge is Principal Research Writer, Office of Information.

farmers, aided by every Federal, State, and local agency that has anything to contribute to the solution of the farmer's problems.

A coordinated approach to better land use on so extensive a scale is new in the United States. There is much to be learned, and there will inevitably be trial and error and more or less friction. These may be reduced by following a principle on which almost everyone would agree—that the desirable method of coordination in a democracy is a system that promotes common understanding based upon facts and reliable interpretations of them.

That principle motivates those who have contributed to this Yearbook on soils. Their aim has been to present facts and interpretations that will promote common understanding.

The book is one of a series of Yearbooks dealing comprehensively with major aspects of modern agriculture. The first two, those for 1936 and 1937, covered the subject of genetics and breeding with almost the full range of crops and animals on farms in the United States. The next book, for 1939, will be concerned with what has been called the newer knowledge of nutrition as it affects both animals and human beings.

Probably no other book has dealt with the soil from so many angles as this Yearbook. It represents genuine collaboration between many men; for example, more than 100 authors have contributed to it. It is an effort to see the subject as a whole—scientific aspects, practical aspects, social and economic aspects; the needs of individuals, groups, and the Nation. It is also another step toward cooperation between the natural sciences and the social sciences. Unless these sciences can learn to speak a common language, there is real danger that they will make modern civilization another Tower of Babel, which tumbled because the specialists did not know how to get together.

One point should be made clear. In several places the Yearbook on soils necessarily deals with national agricultural problems, but it is not in any sense a summing up of official policy. It is a discussion of scientific, economic, and practical factors that must be considered in any policy. Such a discussion would lose its permanent value and its democratic character as a contribution from many minds if an attempt were made to achieve consistency at every point. There is a certain general consistency in the book, but the writers have expressed different individual viewpoints that developed out of their own study and experience. These viewpoints are not to be taken as representing a definitive Department attitude.

Thanks are due to many workers in the State experiment stations and in foreign countries who generously contributed to a preliminary survey designed to bring out the present status of soil research, as well as to those outside the Department who wrote articles for the book. Not all of the material could be used. The committee on soils, appointed to have general charge of the Yearbook, regrets that space limitations made it impossible to include some articles, parts of articles, and statistical compilations of great value in themselves.

THE YEARBOOK IN BRIEF

How to use the land better than we have is at once a national problem, a local problem, and an individual problem. It involves at least five

different elements. The Yearbook is divided into five parts corresponding to these five divisions of subject matter. Part 1, The Nation and the Soil, deals with the problems and causes of soil misuse from the economic and social standpoint, and the possible remedies from the same standpoint. Part 2, The Farmer and the Soil, deals with a wide range of soil-management practices that may be applied by individual farmers. Part 3, Soil and Plant Relationships, deals with the soil requirements of plants and some relations between soil composition and plant composition and functioning. Part 4, Fundamentals of Soil Science, discusses the physical, chemical, and biological nature of the soil, which furnishes the scientific background for dealing with practical problems. Part 5, Soils of the United States, describes the soils of the Nation, including its Territories, on the basis of the work of the Soil Survey Division. A map of the soils of the country, especially prepared for the book, will be found inside the back cover. At the end of the book there is A Glossary of Special Terms and a reference list of the literature cited in various articles.

A summary of the first four parts is given in the following pages so the reader may have a rapid survey of the book as a whole. Naturally, details must be omitted from this broad outline. Part 5, Soils of the United States, is descriptive and not well adapted to summarizing.

The Nation and the Soil

To see the soil problem as a whole requires an effort to determine the purpose of the Nation in its use of soil resources; to find out where this purpose is not being achieved; to discover what causes the failures or shortcomings; and to seek effective remedies.

Most people will agree that the broad underlying purpose guiding the use of soil resources should be "to maintain the highest possible standard of living for the people of the United States." This includes secure farm homes, adequate and stable incomes for farm people, and a continuous and abundant supply of farm products for all of the people. In other words, the soil problem is really a problem of the well-being of people.

But it is not a problem for today only. The well-being of future generations must be secured also if the Nation is to continue to live. One of the great national objectives is to pass the soil on to our descendants as nearly unimpaired as possible.

The Nation, then, looks to the future. But here there may be a conflict between the national interest and the individual interest. In order to make a livelihood now, many people find it necessary to do things to the soil that are not for their own long-time interests or for the interests of posterity. How can these people promote the long-time interest without sacrificing their own present necessities? How can the national interest and the individual interest be reconciled?

This question affects people everywhere, but it is most acute where human misery is most acute—where people are trying to scratch a living from submarginal land unfit for farming. The total income that can be furnished by these areas must be divided among too many families. Both the soil and the people suffer as a consequence.

One group argues that these people must be moved out of the poor areas. But if they are moved to better land, other farmers will have

increased competition. So they must be moved out of farm occupations altogether and into industry, and if there are not enough opportunities for them in industry, opportunities will have to be made by reforming the industrial system. But another group argues just as strongly that these people should be kept in farm occupations. The chances for a modest and secure livelihood in farming are at least as good as in industry, and probably much better. Why jump from the frying pan into the fire? Moreover, it is wise to keep a large rural population. The rate of increase of the total population is declining alarmingly, and rural communities help to offset some of this decline because they have a much higher birth rate than cities.

A third group takes a middle course. They say it is not necessary to make a drastic decision either way. What we should do is, first, to classify certain land areas as definitely nonagricultural according to certain minimum standards. Then, as fast as people move out of these poor areas voluntarily, we should refuse to permit others to come in and take their places. Those who move out should be given help in finding better opportunities elsewhere, mostly in nonfarm occupations. Part-time industrial employment, combined with subsistence farming, might fit many cases, at least if industry and commerce become more decentralized.

This is essentially a policy of gradually clearing out rural slums and retiring land not now needed for production and giving no promise of ever supporting farm families in a decent manner. The middle-of-the-road group does not argue that this is a final or complete solution, but that it is practicable, it would do an enormous amount of good, and it would kill two birds with one stone. It would benefit people today and it would conserve the soil for the future.

But it is not by any means the whole story. Actually there is no one problem of soil misue, no one cause, and no one remedy. All three vary, not only in difference places but at different times.

Problems of Soil Misuse

In the humid parts of the country, the worst problem areas from the standpoint of present human misery are probably in cut-over forest regions and in the hill regions of the East and South. In the cut-over forest regions there is much land unfit for farming, and human effort and public funds are both wasted when attempts are made to farm it. Frequently, settlement is sparse, sometimes consisting of stranded populations left when milling or mining operations stopped. Roads and schools—even poor schools—cost more than they are worth for so few people, and much more than the people can pay; the rest of the State has to foot the bill. Such lands would be more profitable if they were devoted to their best use, which is forest production.

In the hill regions of the Northeast, the farm population was declining in most areas prior to 1930 as farms were abandoned. In most counties in the Southeast, it has been increasing; some hilly areas of poor soils have a density of population greater than the most productive parts of the Corn Belt. The population has backed up here because neither old nor young could find opportunities to leave; and during the depression there was an actual net migration into some of these areas. Many people eke out a bare subsistence from the

land. The productivity of the soil is reduced at an increasingly rapid rate as erosion proceeds.

In the subhumid and arid regions lie the dry-farming areas, the irrigation projects, and the range country. There are relatively prosperous communities in the dry-farming areas—but there is also the dust bowl. A great many farms, even though large by eastern standards, are too small to furnish a livelihood under the prevailing conditions. Human optimism, local pride, commercial interests, the war, and large-scale farming machinery have all played a part in the overdevelopment of some of these communities. In years of high rainfall, production is good and everything booms; then come years of low rainfall, bringing crop failures and widespread ruin. Families by the thousands have migrated in bad years, many of those who remained have had to go on relief, loans could not be repaid, and there is widespread tax delinquency. Wind erosion resulting from plowing up the original sod is serious nearly everywhere except in the eastern part of the region.

Where there have been failures and misuse of the soil on irrigation projects, they have often been due to mistaken judgment or lack of knowledge at the time the project was developed. Irrigation projects in general, according to one study, were in better financial condition during the depression than agriculture as a whole. But when failure does occur it hits hard because of the high cost of irrigated farming.

On range land in the West, both public and private, the heritage of fertile soil has been quite generally squandered by overstocking and grazing at the wrong season. Where the range is damaged by overgrazing, drought takes a heavy toll. Erosion also becomes serious, and flood damage increases. The profits from livestock are reduced, farm living standards are lowered, and homes are abandoned. On the other hand, good management on numerous private ranges and in the national forests proves that this waste of land and people is not necessary.

Much land has been put under cultivation that should never have been used or should have been used differently. Unwise drainage is another example of this. Drainage has been extremely worth while in many cases, but it has also sometimes been a waste of money, especially where the soil was basically unsuited to agricultural production. The State of Minnesota, for example, has had to spend millions of dollars aiding distressed drainage districts established in what were originally swamp areas. In addition, the peaty soil was subject to disastrous fires when drainage had dried it out. Such waste can easily be avoided by leaving unsuitable land in its natural state, developing it as refuges for wildlife, and impounding water instead of draining it away. This is now being done by many States in cooperation with the Bureau of Biological Survey.

These are instances of soil misuse in particular regions and areas. What about soil erosion in the country as a whole? How extensive is it? What are its effects?

An erosion reconnaissance survey of all the land in the United States, agricultural and nonagricultural—something over 1,900,000,000 acres—was made in 1934. A reconnaissance survey is not detailed or precise, but it is useful nevertheless. Among the facts brought out by this survey were these:

(1) On 37 percent—700,500,000 acres—of the total land area, mostly flat, gently undulating, or forested, erosion has been slight; less than one-fourth of the original surface soil has been lost.

(2) On 41 percent—775,600,000 acres—erosion has been moderate; from one-fourth to three-fourths of the original surface soil has been lost.

(3) On 12 percent—225,000,000 acres—erosion has been severe; more than three-fourths of the original surface soil has been lost.

(4) Three percent—57,200,000 acres—of the land area has by now been essentially destroyed for tillage.

(5) About 7½ percent—144,700,000 acres—consists of mesas, canyons, scablands, badlands, and rough mountain land. Overgrazing and other abuses on some of this land have caused moderate to severe erosion.

So much for the land area as a whole. In 1937 State and Federal workers made a Nation-wide appraisal of the condition and needs of agricultural land only. This resulted in the following estimates, assuming a price level for agricultural commodities equal to that in the period 1921–36:

(1) The present cropland area of the United States (1935 Census of Agriculture) is 415,334,931 acres. Of this, practically 61 percent—about 253,000,000 acres—is either subject to continued erosion or is of such poor quality as not to return a satisfactory income to farmers at the price levels assumed. To continue present practices on the part of this land subject to erosion is to mine it and progressively destroy it. Over half of it is badly in need of good soil conservation practices to prevent serious damage.

(2) It follows that only about 39 percent—some 161,000,000 acres—of the present cropland area can be safely cultivated under prevailing practices or should be cultivated under the price levels assumed. But some land that is not now in cultivation could be safely cultivated. Adding this to the 39 percent gives a total of about 211,800,000 acres as the maximum that can be safely cultivated under prevailing practices. This is equivalent to a little less than half of the present cropland area. Under prevailing practices, then, our agricultural plant would have to be reduced by half if we wanted to save the soil.

(3) But agricultural practices change; and under the best practices, fully 82 percent—339,000,000 acres—of the present cropland area can be safely cultivated and should yield a satisfactory return at the price levels assumed. Even under these practices, however, over 76,000,000 acres—18 percent of the present cropland area—should be retired as submarginal or not suited for production at present.

(4) But if the need arose, we could more than make up for this retired submarginal land, because with the best practices we could cultivate some 108,400,000 acres that are now in plowable pasture, brush, or timber, or are improvable by drainage or irrigation. This might be called the Nation's production reserve. It brings the potential resources of cultivable land, under the best practices, up to 447,466,000 acres, which is a little more than the cropland area of today.

One other factor needs to be considered in connection with these figures. Adopting the best practices would almost certainly increase production on land now cultivated, just as continued soil waste will decrease it and add to production costs. Soil management, then, is not a separate problem. Through its effect on production, it is part of the whole agricultural economy.

It should perhaps be emphasized that the figures given above are estimates. More complete data are needed on the effect of both soil erosion and conservation practices. For example, there is little in the way of accurate information on the effects of erosion in reducing production per acre. Average figures for regions or for the country as a whole have little meaning. They may show that production has been maintained or has even increased in a certain region or for a certain crop. Does this mean that soil erosion has had no effect?

No, because when land deteriorates until it can no longer be worked profitably, production tends to move to better land. Moreover, improved cultural techniques, the increased use of fertilizers, better control of diseases and insects, and the breeding of better plants have all tended to offset the effects of soil deterioration. In spite of these improvements, average crop yields have not increased. What we have gained in one way, we have lost in another.

If there are no accurate crop-production figures to prove this point, there are convincing experimental data which show that yields decline when crops are removed without adding manure or fertilizer to the soil; that the nitrogen content of the soil decreases with continuous cropping; that plant nutrients are removed by erosion, to the detriment of crop yields; and that it is extremely difficult to restore the fertility of eroded soil even when large amounts of fertilizer are used and green-manure crops are plowed under.

Accurate figures are similarly lacking to show the full effect of erosion on floods, navigation, water-power development, and water conservation for the country as a whole. Certain concrete examples, however, give impressive indirect evidence. For instance, in a certain part of the Appalachian region the maximum flood flow from forested watersheds during a little over 3 years was only 6 cubic feet per second per square mile. At no time did it assume critical flood proportions. From abandoned agricultural land, on the other hand, the flow was 403 cubic feet per second per square mile, and from gullied pasture land, 785 cubic feet. In numerous instances the flow in these latter areas assumed serious flood proportions. This is not to say that eroded land is the sole cause of floods, but it is undoubtedly a contributing cause.

Examples of the filling up of stream channels by sediment from eroding land can also be given, especially for the smaller streams. The silting of reservoirs may often be traced directly to soil erosion; in many cases the silt is piling up at a rate that will exhaust the water-storage capacity of the reservoirs within a comparatively few years. Some water-power dams and reservoirs have already lost all effectiveness as a result of silting. It has been estimated that some 3,000,000,000 tons of soil are washed annually from overgrazed pastures and cultivated or barren fields, to be poured into streams, harbors, reservoirs, lakes, and oceans, or deposited on bottom lands and flood plains.

Some Causes of Soil Misuse

Among the causes of this misuse of the soil and consequent waste of human resources, lack of knowledge on the part of individuals undoubtedly plays a large part. But even if all farmers thoroughly understood the consequences to themselves of the type of land use they are practicing and had perfect knowledge of soil-conservation techniques, a large number would still be unable to put the knowledge fully into practice. Social and economic limitations would prevent them from doing certain things they knew ought to be done. These limitations are themselves causes of soil misuse.

First among them is our traditional attitude toward the land. In the past this country has not had a comprehensive or well-thought-out

land policy. We had an abundance of resources and a strong tendency toward individualism. We believed that every man had a right to the unrestricted ownership of a piece of earth. Our land policy consisted in disposing of the public domain as speedily as possible. This was natural; the primary need then was to subdue a wilderness. But in following out this policy, we sometimes frustrated our own fundamental aims. For example, corporations and speculators acquired large acreages, and thousands of acres of the finest forest land were secured by exploiters and promptly devastated. Without guidance, some settlers took up poor land, and on the Great Plains the homestead grants were not large enough for a livelihood. Land speculation eventually tended to favor absentee owners and to make many farmers regard the land primarily as a source of quick profit. The prevailing system of inheritance worked toward the breaking up of farms into too small units in some areas; in others it encouraged tenancy and the passing of ownership to people who had moved off the farm.

Present methods of granting public aid to distressed rural areas would help to perpetuate evils if no effort were made to find and correct the causes that make aid necessary. This is true of direct relief, work relief, drought relief, crop loans, feed and seed loans, rural rehabilitation loans, Agricultural Adjustment Administration benefits in some cases, and State aids to communities too poor to pay for public services. The danger lies in continuing emergency measures indefinitely and thereby covering up the conditions that necessitate them.

In many European countries, including Great Britain, the Scandinavian countries, France, Switzerland, Germany, and Austria, the movement to get rid of feudal methods in favor of liberalism and individualism developed somewhat as it did in the United States. As here, there were many excellent results in agriculture; forces of industry and thrift were set free, individual responsibility was fostered, large estates were broken up, farms were improved with borrowed capital. But likewise there was speculation, excessive subdivision, and overburdening with debt. Many landholders found themselves owners in name only, in reality debt slaves. The greater density of population and other factors made the need for efficient land use more quickly and urgently felt in these countries than in the United States. In all of them within the past few years attempts have been made to regulate land use in the public interest through laws affecting inheritance, subdivision, debt, and management.

Another group of causes of land misuse in the United States has to do with defects in farming systems on land suited to farming, and defects in the tenancy system.

Some farming systems are inherently soil conserving; others are not unless special practices are followed. Moreover, this country is so diverse in soil, climate, and other ways that it can be divided into at least 500 type-of-farming areas. In each type of farming there are certain most-favorable combinations of soil, slope, climate, use of labor-power and equipment, and managerial ability. Departure from the optimum at any of these points lessens opportunities for income, economical operation, and soil conservation. This is especially true

where attempts are made to follow a system of farming not suited to the region, and also in the case of the small-farm operator who has to use his land to the limit. If a farmer is to make enough to live on without punishing the soil, the first requisite is that he have adequate soil and water resources.

Three facts stand out as of major significance in connection with tenancy. (1) It has grown with great rapidity; the number of tenant-operated farms increased from 1,024,601 in 1880 to 2,865,155 in 1935, and from 25.6 percent of all farms to 42.1 percent. (2) Tenant farms ordinarily have a larger proportion of land in soil-depleting cash crops and a smaller proportion in soil-conserving crops than owner-operated farms; this is proved by several studies. (3) It is not tenancy itself that discourages soil conservation but the prevailing conditions under which tenants have to operate. Farms are ordinarily rented for a year at a time without assurance of renewal. The tenant is here today, he has gone tomorrow, not always because he wants to but because the tenancy system too often works that way. Under these conditions he must produce cash crops, and what happens to the soil is not his concern. If he makes permanent improvements he is not compensated for them; in fact he is likely to lose the place to a higher bidder. The net result of the system has been to make neither tenant nor owner responsible for good soil management.

Certain imperfections in agricultural finance, notably in mortgages and taxation, have also tended to discourage soil conservation.

The necessity of meeting payments on a mortgage that is unduly burdensome has caused many farmers to push the production of cash crops to the limit and to avoid any expense for soil-conserving practices. Most mortgages contain no provisions for preserving soil fertility; their terms are a heritage from the days when this was not considered necessary. Until a few years ago, rising land values were taken for granted and an increasing mortgage debt caused little concern. But as the long decline that began in 1920 got more and more farmers into serious trouble, the shortcomings of the prevailing finance methods were widely recognized.

In 1935, 42 percent of all owner-occupied farms and about 25 percent of all rented farms were mortgaged. Obviously, mortgage terms may have a widespread influence. There are four ways in particular in which they may encourage soil depletion, increase tenancy by causing owners to lose their farms, and discourage tenants from becoming owners: (1) Too heavy a debt, based on too high land values, which is disastrous when prices decline; (2) the short-term straight mortgage, which is difficult to refinance during periods of economic stringency; (3) too high interest rates, which result in charges greater than the rate that can be earned by the farm; and (4) too low interest rates, when they are capitalized in too high land values.

The property tax also aggravates the tendency toward exploiting land resources. In contrast with urban enterprise, farming depends on a relatively large investment in land. Thus the property tax, which is primarily on real estate, tends to have a greater effect in intensifying the financial difficulties of farmers and those engaged in timber enterprises.

Partly, this effect arises from the nature of the property tax itself. It is based on value and does not fluctuate with income, which makes it bear especially hard on farmers during lengthy periods of low income, and on forest owners during the time when young or cut-over timberlands need to be built up. Partly also, the effect is due to faulty administration. For example, studies show that there are great inequalities in property-tax assessments and an almost universal tendency to overvalue land that brings a low price per acre. There are also many overlapping jurisdictions in local tax administration. All of these factors have a generally adverse effect on permanent soil maintenance by increasing taxes, particularly on the poorer lands, and making it necessary to turn as much land as possible to uses that will produce ready cash for tax payments.

In addition to the causes of soil misuse discussed so far, there are others that lead to the same result less directly. These include instability of production, prices, and income in agriculture; the fluctuations and inequalities in the general economy; and the lack of balance between industry and agriculture.

Instability in agriculture itself includes most aspects of the farm business. There are wide fluctuations in the acreage planted to individual crops as farmers try to adjust themselves to changing economic conditions; in yields per acre, according to weather conditions; in storage stocks; in domestic and foreign demand for farm products. Cyclical fluctuations in certain branches of agriculture—notably cotton, wheat, pork, dairy, and beef production—have been growing more violent in recent years. From the standpoint of soil use, these fluctuations, on the one hand, are responsible for opening up large areas to speculative farming during periods of temporary prosperity; on the other, they restrict the amount of money the farmer has available for long-time improvements during periods of hardship.

Some of these uncertainties are hazards peculiar to farming and call for distinctively agricultural remedies. Others go back to general conditions that affect the whole economy, of which agriculture is only a part. Among the latter are the slowing down of population growth in the Western Hemisphere; economic nationalism in many countries and the desire for self-sufficiency, which result in sharp pressure for home production and reduced need for imports; the profound economic distortion produced by the World War—including overexpansion of agriculture—with the subsequent recovery and collapse; the generous wartime and post-war lending policies of the United States, followed by high tariffs which made it impossible for foreign countries to repay the loans in goods and hampered the exchange of goods for agricultural products; and the alternating periods of prosperity and depression known as the business cycle.

In industry, these things are reflected in collapse of investment markets, financial bankruptcy, widespread unemployment, and deterioration of plant and equipment. In agriculture they are reflected in lower standards of living, mortgage and tax delinquency, loss of property, and abuse of the soil. The upshot is that farmers are vitally concerned in efforts to counteract these evils through monetary and credit policies, taxation and public works, and reciprocal agreements designed to enlarge foreign trade.

An important point here is the unbalance between agriculture and industry, which may be traced to the differences in organization in the two fields. The bulk of agricultural production is carried on by millions of individual farmers. The bulk of industrial production is carried on by a few large corporations, which probably control something like a quarter of the wealth of the country. What is the significance of this from the standpoint of agriculture? Simply that today a few corporations exercise a powerful control over industrial production and prices. Competition is greatly reduced, and the tendency is to meet a drop in consumer purchasing power not by lowering prices but by curtailing production and reducing employment. This rigidity of prices still further lowers consumer purchasing power and aggravates the situation of farmers. In the past, they have continued to produce at a generally high level and have taken their punishment in the form of reduced prices, which at least tended to increase the purchasing power of the consumer. During the recent depression, farmers were forced to reduce production to bring about some measure of balance with industry. But this must be considered an emergency solution. The real problem is to achieve the opposite kind of balance—that is, to maintain industrial production in full swing so that agricultural production may keep pace with it on the basis of abundance.

Remedies and Preventives

This account of the problems and the causes of soil misuse from the national standpoint is not presented as a chamber of horrors but as a diagnosis made for the purpose of seeing what obstacles must be overcome to insure better soil use. The fact that public opinion has been aroused to attack the obstacles gives ground for optimism.

Education must rank as the first remedy. The United States is a democracy; it does not accomplish ends by handing down decrees from above, but by the initiative and with the consent of the citizens, who must first know what they want and how to achieve it.

Education includes good schools in poor areas as a means of imbuing young people with the ambition to seek better opportunities elsewhere; vocational education to train them for occupations other than farming; and agricultural education that will show those who remain the needs of the soil and the adjustments in agricultural practice required to conserve it. Going further, education is also the means for bringing about a widespread change in the attitudes of people toward the soil—a process in which the schools, the press, the pulpit, the radio, the motion picture, and the discussion group all have a part to play. Where the land has been abused for generations, it will not be easy to develop the necessary knowledge, convictions, and attitudes, nor will it be done quickly.

Outside of the schools there are two principal agencies that carry on educational work through direct contacts with farmers. They deal with local problems, yet see these also as part of the broader national problem.

The county agents of the Extension Service form a connecting link between farm people and the research agencies—the State experiment stations and the Department of Agriculture. These agents carry on

demonstration work and use many other means of education, including bulletins, newspaper articles, motion pictures, radio talks, exhibits, talks at meetings, and discussion groups. They have played an active part in the broad soil conservation program carried on in the Tennessee Valley, of which one of the most significant aspects is the practical testing, on a wide scale, of new phosphorus fertilizer products made by new processes. These fertilizer materials are furnished free by the Tennessee Valley Authority for use on selected demonstration farms, with the cooperating farmers in the community paying the cost of the transportation from Muscle Shoals. The use of the phosphorus is coordinated with many other soil-conserving practices.

The Soil Conservation Service also carries on educational work through soil conservation demonstrations in selected watersheds throughout the country. This work is new and it is an outcome of the recent recognition that soil erosion and flood control are major national problems. Each demonstration area covers about 25,000 acres, and the actual demonstration is carried out on the farms of those who agree to cooperate. A staff of technicians works with these farmers, analyzing the erosion-control problem, formulating an effective plan to deal with it, and helping each farmer to put the plan fully into effect. A cooperative agreement covers a period of 5 years. Ordinarily the Government furnishes not more than half the required materials and supplies and if necessary some additional labor from Civilian Conservation Corps camps or elsewhere. In many cases problems that appeared impossible are being effectively solved; an attitude of despair has been changed to one of hope. The important point, however, is not what is accomplished for a relatively few individual farmers. It lies in proving what can be done, as a practical matter, so that other individuals and groups will do likewise.

Research goes hand in hand with education. Because agriculture in the United States is so complicated and diverse, a broad research program is especially important in this country. But for the same reason, conditions are especially favorable here for developing agriculture to a very high level. Lack of fundamental data limits future progress. If soil science has been slow to develop in this country, however, it is because soil problems were not generally recognized until so late.

What, in brief, are the broad lines of investigation needed in a research program? It should identify and map soils in the field; determine the characteristics of the soil types from every angle; investigate the responses of each type to the known management practices; and determine its use capabilities on the basis of the scientific data and the accumulated experience of farmers. Some of this work has been in progress for the past 40 years—notably the mapping of soils, now carried on by the Soil Survey Division—but also much of the earlier work needs to be supplemented to fit the more precise needs of present-day analysis. There are two things the soil scientist would stress—not to oversimplify the soil problem and generalize from too few particulars; and not to tie the scientist too closely to practical programs, but to let him pursue his researches wherever the facts may lead.

One of the major functions of soil research is to furnish a solid foundation for land-use classification, which in turn develops into

land-use planning. As a Nation we are just beginning to think in terms of planning the use of the land. Not until areas are at least roughly classified as suitable or not suitable for farming, and if suitable, for what kind of farming and what size of farm, will it be possible to prevent the recurrence of tragic mistakes evident in the acute problem spots of today. If planning is to be most effective, however, both local and national farm leaders must participate. Technicians and public officials should not attempt it alone. It is for this reason that county agricultural planning committees have recently been established in most agricultural counties of the Nation.

For the present, the job is to no small extent one of coordination. A good deal of information exists, but it is scattered and in some cases contradictory, and it needs to be supplemented by more systematic fact-gathering. A good many agencies, local, State, and national, are concerned with land use, but they sometimes work at cross purposes or duplicate one another's efforts. The immediate need is to bring some order out of this chaos. As a step in that direction, an Office of Land Use Coordination has been set up in the Department of Agriculture.

But education, research, and planning are not enough by themselves. They are continuous processes, but they must be supplemented and made effective by action programs.

The most obvious place for the application of direct remedies for soil misuse is on publicly owned land, of which there are hundreds of millions of acres in the public domain, the national forests, and the areas belonging to States, counties, and towns. This soil at least should be well managed, though as a matter of fact much of it has not been.

The 162,000,000 acres of public domain in the West consists of land so poor that nobody would take it as a gift on a homestead basis. Yet paradoxically it supports 1½ million horses and cattle and 6½ million sheep and goats 7 months out of every year; and it is a substantial part of the watersheds of many western streams, and therefore important in flood control. Through more than 50 years of overgrazing, 19 acres out of every 20 are now eroded, half of them severely, and the grass cover has been severely depleted as compared with its original condition. The great need today is to restore this range cover. It can be done by such means as regulating the number of livestock within safe limits, regulating the seasons of use, reseeding especially bad areas, and fencing, water development, and other management devices. The new Taylor Grazing Act finally makes this possible, but it will require many years to restore the land.

The national forests contain 175,000,000 acres of forest and range land. In 1905 the Secretary of Agriculture laid down the policy that this land was "to be devoted to its most productive use for the permanent good of the whole people, and not for the temporary benefit of individuals or companies." The mandate is simple, straightforward, flexible, and permanent. The power is there; the problem is to apply it by developing sound methods of managing soil and vegetation. This is being done, in the forests and on the forest range, through a combined program of research and practice which is pushed as far as funds will permit.

Of the land originally granted to them by the Federal Government, the States still hold the acreages that were not good enough to attract private buyers. This land is held for sale, though it would be more sensible to use much of it for forestry, grazing, or recreation. In addition, tax-delinquent land becomes State property in 19 States, county property in 23, and town property in 6. The total tax-delinquent land publicly owned may amount to 50,000,000 acres, with millions more subject to confiscation for delinquency.

In many or most such cases the land is submarginal and unprofitable for private owners. The time has come to recognize the fact that this kind of land will inevitably become public property. The problem then is to work out clean-cut procedures for the State or other governmental unit to acquire title, settle the tax equities, and apply a definite policy of administration, probably using the land for forests, grazing, public game preserves, and parks. One difficulty is to block up scattered areas into practicable units, and this calls for exchange with public or private owners, or purchase, to fill in gaps.

In general, it may be said that Federal purchase of land to correct maladjustments in agriculture, especially where there is a history of farm abandonment and stranded families, should be confined to cases where no other measures would be effective. The Department of Agriculture initiated a policy of land purchase in 1934 for this purpose, and this has been extended through the land-purchase program under the Bankhead-Jones Farm Tenant Act of 1937. Such programs, of course, must include provisions for the relocation and rehabilitation of families moved off the land acquired by the Government.

A survey of the possibilities for regulating the use of private land shows that several things may be done. Each has a limited but worth-while field of usefulness. Most of the efforts in this direction are new.

First there is zoning. Zoning ordinances, which are an established practice in towns and cities, depend on what is commonly known as the police power—that is, the power of the State to regulate private conduct where necessary to protect public health, safety, morals, or welfare. Urban zoning is applied to harmonize land uses, relieve congestion, and stabilize property values. Rural zoning is new. It has been established in Wisconsin since 1929 and in Michigan since 1935. Unlike such regulations as weed laws and corn-borer control, it is not State-wide and mandatory but local and permissive. In Wisconsin it has been applied mainly to prevent the settlement of remote nonagricultural areas. It might be extended to good farming areas to keep agricultural communities compact, minimize school and road costs, postpone the use of second-grade land, prevent the resettlement of abandoned land, and protect streams and lakes against silting or pollution. It would probably not be effective in promoting the best use of land already in farms, or in controlling erosion.

In the West, the development of grazing associations offers a new means of regulating the use of grazing lands through the cooperative action of stockmen. These associations have recently been organized in Montana, North Dakota, South Dakota, Wyoming, Colorado, Idaho, and Oregon. Essentially, they rest upon a private contract between members to manage a given area, centralize the leasing of

lands, work out plans for range improvement, and develop rules and procedures for distributing grazing privileges. The development may play an important part in future agricultural adjustments in the Great Plains region.

The soil conservation districts laws are another new development. To enable farmers within a watershed or other natural area to cooperate in applying erosion-control measures uniformly throughout the area, a standard act was devised by the Department of Agriculture in cooperation with the States, and recommended to the States by the President in 1937. By June 1, 1938, 25 States had adopted legislation based on the act, and 59 soil conservation districts had been organized.

The act requires a petition from 25 land occupiers to establish a district and a favorable vote from a majority of all land occupiers before it can finally be established. Once established, a district can carry on research, conduct demonstration projects, apply preventive and control measures, enter into contracts with farmers and give them financial and other assistance, take over State and Federal erosion-control projects, recommend land-use plans for soil conservation, and formulate an ordinance prescribing land-use regulations—which cannot go into effect, however, until it has been submitted to a referendum of land occupiers and approved by a majority of the votes cast. The regulations may be amended or repealed by referendum. Failure to observe the regulations is punishable by a fine, and a court may order that the necessary work be done by the supervisor and costs collected from the land occupier. A board of adjustment is provided and its decisions are subject to review in the local courts. Funds may be provided only by direct appropriations out of the State treasury or grants-in-aid by a Federal agency.

Resettlement as a policy for aiding distressed farm families at present bristles with questions. The poverty and lack of opportunity in problem areas needs no proof. Neither does the fact that it was largely the result of unguided settlement in the first place. But how many people really want to migrate? What localities offer them the best opportunities? Is there any assurance that the better location of today will be better tomorrow? Such basic questions as these—there are many others—make for hesitation in applying an extensive program of moving people out of the problem areas. Much more study will be needed before resettlement can have more than a limited application.

In the case of reclamation projects—the irrigation of arid lands in particular—several changes in policy can be made that would prevent the repetition of certain past failures and shortcomings. The technical questions involved in successful irrigation are considered elsewhere. Here it may be said briefly that speculation in irrigated lands should be eliminated from Federal projects; the Federal Government should not participate in any project that is not proved by careful investigation to be economically feasible; assessment of charges against settlers should be adjusted better than it has sometimes been in the past; costs for power development and flood control should be allocated elsewhere, not charged to settlers; and a responsible agency should have the specific function of getting a full quota of settlers to

the project as quickly as possible. Some of these policies have been put into effect.

Three faults of the tenancy system were brought out in the previous section—it provides no incentive for the tenant to maintain or improve the farm; in some instances it forces him to take a loss for improvements; and there are many miscellaneous maladjustments in lease contracts. These faults suggest their own remedies.

(1) State laws might increase the security of the tenant by requiring that leases must be in the form of written contracts running for a period of 5 years, terminable at the end of any year upon 6 months' notice by either party, and setting forth in full the duties and responsibilities of both parties. An inexpensive legal mechanism for quickly settling minor differences between landlord and tenant should also be provided. The landlord's lien for the collection of cash rent might be limited by statute, particularly in the case of crop failure or economic depression.

(2) The tenant's financial interest in improvements might be protected by giving him the right to take away removable improvements and receive compensation for those not removable. At the same time, the landlord should be compensated, in the form of higher rent, for improvements made by him. A tenant should be penalized for unwarranted deterioration, but on the other hand he should be compensated, when he leaves the farm, for unexhausted improvements. This compensation might be paid by the new incoming tenant, perhaps over a period of time.

(3) Miscellaneous maladjustments in tenancy are mostly local and due to local peculiarities. They need detailed study and probably could best be corrected through educational programs.

In the field of agricultural finance there is need for property tax reforms, better management of farm credit, and changes in mortgage financing. There are two fundamental methods of lightening the tax burden.

(1) The revenue requirements of local governments might be reduced by increasing efficiency through reorganization, consolidation of units, and reallocation of functions; zoning land to save costs of schools and roads; shifting a greater part of the cost of some functions, such as education, to the State; and such other means as greater use of trained administrators, better financial practices, more State supervision, and closer citizen control through the short ballot, the budget, and full publicity. It is very important that such changes should be accompanied by centralization of assessment in larger units, and better appraisal methods.

(2) Less reliance might be placed on property taxes for revenue and more on other forms of taxation, particularly the income tax. In addition, there might be special tax arrangements for deferred-income property such as forest land while it is being brought into bearing.

The principal evil of farm credit from the standpoint of soil use seems to be the assumption by the farmer of a debt that is beyond the earning capacity of the farm to pay. To correct this, more emphasis should be placed on the estimated earning capacity of the property and less on the speculative market value of the tangible assets; maximum and minimum commodity price limits should be set in estimating earning capacity to avoid extremes in periods of boom or depression; more attention should be given to regulating the maturity and terms of loans in such periods; and relief, bounties, grants, and subsidies should be clearly recognized as such and not confused with credit.

Farm mortgages should be made to help rather than hinder soil conservation. Good care and management of the farm is of first importance to both borrower and lender; provisions to insure this for the lender could be definitely included in the mortgage contract in

return for concessions that would prevent undue financial pressure on the borrower in times of emergency. The average total annual payment required to amortize a mortgage should not exceed the average share of the income that can be devoted to this purpose without skimping unduly on other expenses. The requirement for fixed annual payments that prevails in the commercial world is not suited to farming, where income is highly variable; instead, it should be practicable to make the loan payable on or before the expiration of a designated long term, and to vary the amount of annual payments with the major fluctuations in farm income. Such an arrangement is provided in the Bankhead-Jones Act. There should of course be a fair interest rate, safeguards against overextension of debt, and assurance of the qualifications of the borrower.

Such changes as those suggested throughout this discussion are desirable in themselves as well as for their effect on soil conservation. But most of them could only be brought about gradually. Meanwhile there is need to make an effective start in soil conservation work at once and on a fairly wide scale. Many farmers, however, cannot afford the necessary expense, especially in a depression period, or they are not convinced that they have anything to gain by better practices. To meet these obstacles, the device of giving direct aid to farmers, in the form of conditional grants and of technical and other services, has been used.

Grants-in-aid for various purposes—child welfare, public health, and so on—are not new, but they were first used for soil conservation in 1936, under the Soil Conservation and Domestic Allotment Act. On the basis of the experience so far, it appears that such payments can be effective if farmers are recompensed for two-thirds to three-fourths of the costs or sacrifices involved in carrying out practices beyond those they would ordinarily carry out. In acute problem areas where fundamental changes in land use are needed, such grants can probably do no more than ameliorate conditions somewhat. Whether conditional grants have a permanent place in soil conservation is a question that will have to be decided after further experience.

Experience with technical and other aids given to farmers by the Soil Conservation Service, the Civilian Conservation Corps, and the Tennessee Valley Authority has also been short. So far as the donation of material and equipment is concerned, it appears that farmers need less and less help as a conservation program proceeds and they see its benefits. Those who have carried on this work believe there is no question but that it has speeded up the adoption of erosion control and soil conservation practices, but there is doubt as to whether the kind of help that has been given to individuals so far would be justified on more than a demonstration basis. After responsible soil conservation districts have been organized, however, this type of Government aid could probably play a permanent and very important part in furnishing services—particularly technical assistance—that would advance the public welfare but that could not readily be provided by individual farmers.

In the discussion of the obstacles to soil conservation, it was shown that one of the major factors is economic instability—both the instability peculiar to agriculture, and industrial and financial instability

that profoundly affects agriculture. Without efforts to correct these deeper causes, any attack on the soil conservation problem in the Nation as a whole can be only piecemeal and partial. It need hardly be said, however, that soil conservation is only one more reason for making these efforts, which are vital to national well-being from every standpoint.

On the strictly agricultural front, the main attack on the problem in recent years has been through the Agricultural Adjustment Act. From its early emergency stages and through legal vicissitudes, this has evolved into what is essentially a three-point program, the goal of which is a higher and more stable farm income:

(1) Voluntary acreage control. This gives a moderate adjustment of crop acreage but not enough to equalize the flow of products to market from year to year.

(2) Commodity loans and crop insurance. These are devices to induce the storage instead of the marketing of surpluses in years of high yield. The stored products are marketed in years of low yield. The method is intended to equalize the flow of products, and thus stabilize and improve income, under ordinary conditions.

(3) Marketing quotas to take care of emergency conditions. These are aimed to prevent the dumping of unusually heavy storage stocks, which might be built up if there were several successive years of high yields.

Such a program is not simple to carry out, and no responsible person believes that by itself it is the complete solution for instability in agriculture. It requires taking precautions against the abuse of commodity loans, and against capitalizing improved income in the form of too high land values; and any program agriculture adopts has to be integrated into broader policies for the Nation as a whole.

On this broader economic front, everyone is familiar with the efforts that have been made since the 1929 depression to achieve greater stability. These things are beyond the scope of this book except insofar as it is necessary to point out their real relationship to soil use and agricultural welfare. Whatever the individual farmer's viewpoint on specific national policies may be, he cannot escape the hard fact that he and his farm and his market are directly affected by the income of the great mass of workers who are also the great mass of consumers, by industrial unemployment, by tariffs and the state of international trade, by national fiscal policies, by the violent fluctuations of the economic cycle.

Everyone wants to see greater stability and a higher standard of living. There is no universal agreement on how to achieve them. The effort may proceed on democratic lines or on the lines of dictatorship. The former is the choice of the United States. It means that national policies must rest on the broadest possible popular base, and this emphasizes the overwhelming need for intelligent, effective, and continuous action by organizations of farmers, consumers, and workers.

Finally, it is important to realize clearly that soil conservation has legal as well as economic, social, and individual aspects. Agricultural programs can be put into effect only within a definite constitutional framework, and the final arbiter in deciding whether they fit this framework is the Supreme Court. In the writing of such legislation as the soil conservation districts laws, which are administered by the States, and the agricultural adjustment legislation, administered by

the Federal Government, constitutional limitations must be kept in mind at every step; and not only constitutional limitations, but the past rulings of the Court as to what these limitations really are and what they permit. A study of how such legislation is prepared is a revelation in the difficulties and intricacies involved in turning policy into law. How important this step is may be judged by the Supreme Court's decision on the original Agricultural Adjustment Act. That decision has several instructive aspects.

But in interpreting the law the Court reflects deeper social forces, as the dissenting opinion, in which three judges expressed a viewpoint opposite to that of six judges, makes abundantly clear. It is these deeper forces that must be fully understood if the Nation is to move toward any great end such as adequate conservation and use of its soil resources.

The Farmer and the Soil

Good soil management, in the sense of maintaining fertility and productivity, depends upon a number of relatively simple practices. Broadly, five things are of first importance: (1) Suitable tillage; (2) maintaining the supply of organic matter, principally by the use of proper rotations and cover crops, including legumes; (3) correcting soil acidity in the humid regions; (4) providing an adequate supply of phosphorus; and (5) using mechanical measures to control erosion where rotation and cover cropping are not sufficient. This applies to general farming in most regions. In some areas and for special crops, there are special problems associated with water supply, drainage, nitrogen, potash, and certain minerals.

Accurate analysis of the conditions that make this or that practice desirable, however, is not always easy, especially in a country with as many different conditions as the United States. Nor is it easy to work out the variations in details that make so much difference in economical operation.

Tillage and Tillage Implements

Tillage has three main purposes: The preparation of a suitable seedbed, destruction of plants that would compete with growing crops, and improvement in the physical condition of the soil. Under the right conditions it may also help to conserve nitrogen or make it more quickly available, control plant diseases and insects, save moisture, and prevent erosion by wind and water. The amount, the time, and the kind of tillage are all of vital importance, but they depend on climate, lay of the land, soil, crop, and type of farming, and no general rule applies. In humid regions subject to erosion and leaching, for example, the soil should have a plant cover during the dormant or rainy season to prevent erosion; in certain arid regions it should be left bare to collect and conserve moisture.

Some 2½ billion horsepower-hours are used annually on farms in the United States for plowing and listing alone. Obviously the choice of the right tools is a large factor in using this energy most effectively. Today, tillage implements are available for many different conditions.

Moldboard plows include types for shallow or deep plowing; hillside plows; two-way moldboards that leave no dead furrow; special bottoms

for sticky and heavy soils, black lands, tough sod, and stubble; speed bottoms for use with fast tractors; attachments for trash covering; subsoil plows and chisels for semiarid regions and hardpan; middle busters and listers for ridging; basin-forming lister attachments, which make small dams at regular intervals to hold water in the furrows. Disk plows also include various sizes and types; they are primarily useful in hard and dry or sticky soils where a moldboard will not scour, or in loose soils full of roots.

Tools for surface tillage include disk harrows, of which there are several special types; spike-tooth harrows for breaking clods and leveling; spring-tooth harrows; clod crushers and mulchers of several types; special tools for seedbed preparation. Cultivators include those with shovels or sweeps and those with spring teeth; the rotary hoe with projecting fingers; field cultivators with long, slender teeth; rod weeders, which wrap weeds around a rotating rod; and such special machines as those for narrow rows, for thinning sugar beets by cross blocking, and for market gardening.

In spite of the great variety of implements, improvements in tillage machinery and methods are still needed. Some improved methods have been developed as a result of recent comparisons and cost analyses in the field.

Soil Deficiencies

Among soil deficiencies that affect productiveness, those of organic matter, nitrogen, phosphorus, and potassium are of special importance.

In general, the fertility of virgin soils is associated with the continuous supply of organic matter they receive from native vegetation, which is in balance with other factors. The mere act of cultivation tends to reduce the supply in many soils because the activity of "bacterial wrecking crews" is greatly speeded up by the additional oxygen furnished in stirring the soil. These microscopic organisms then break down the organic matter at a more rapid rate until it is decomposed into its simplest elements and disappears. Since agricultural crops are generally removed instead of being left to decay, not enough raw material is added to the soil each year to maintain the natural balance. This rapid reduction under exploitive types of management may occur even without erosion. One result is a serious loss of nitrogen, which is largely stored in organic matter and released by decay. Another is a serious change in the structure of the soil, which becomes more finely divided and compact as the amount of organic matter is decreased.

Such reductions in productivity are neither inevitable nor necessary. Yet this has happened so extensively in certain parts of the United States that the virgin productivity of the soil has been profoundly changed. To retain or increase the productivity that is left, it will be imperative to provide for an adequate and regular return of organic matter to the soil in the future. The best organic-matter insurance is the extensive use of grass and legumes, in rotations or in long-time pasture. Before they can be grown successfully, however, it may often be necessary to provide favorable conditions by the use of lime and phosphorus. With proper practices, there is no reason why the supply of organic matter cannot be adequately maintained or in

some cases increased in the soils of the United States in which it is now needed.

Nitrogen is a fundamental element in the building of protein, the stuff of life. Under natural conditions, it does not exist in the soil like the minerals but must be obtained from the air. But plants in general cannot get it from the air or use it in its pure form; it must first be "fixed," that is, combined with another element or other elements, as it is in nitrates, nitrites, and ammonia. This fixing is done by the electric discharges of lightning and by nitrogen-fixing bacteria in the soil. These are the fundamental sources of supply. But nitrogen already built into the protein of living tissues is also returned to the soil in excreta and in the dead bodies of organisms, and it is drawn from this storehouse and used over and over again by plants. The amount naturally present in a soil therefore tends to vary with the content of organic matter, which is greater in the cooler regions where decomposition proceeds more slowly.

In some forms nitrogen is easily dissolved, and it is therefore readily leached out of the surface soil. Large quantities are also removed by crop plants. Soil erosion removes nitrogen along with other plant nutrients. One estimate indicates that, in spite of replacements, the net annual loss of nitrogen from the soils of the United States amounts to 6,500,000 tons. While any such estimate must admittedly be partly guesswork, it emphasizes the need for conserving nitrogen by every means, and particularly by an adequate return of organic matter to the soil.

Low crop production, however, is due more often to a lack of phosphorus than of any other element. Most soils respond to additions of phosphorus, and this is especially true of acid clay soils low in organic matter; though recent work indicates that the soils of the Great Plains often show an even greater response to phosphorus applications than soils in the East. The United States is today the chief producer of superphosphates, and half the tonnage of fertilizers used by farmers in this country consists of phosphorus materials; but the amount used is still only a small percentage of that needed.

Phosphorus deficiency in soils may be due to a relatively low total supply, removal by crops and by erosion, or low availability of the phosphorus in the soil. The last two reasons are the most important.

When crops, livestock, and livestock products are sold off the farm, the phosphorus they have taken from the soil goes with them, to the extent of 2,000,000 tons a year for the country as a whole. Naturally it is not possible to reduce this particular loss, but it is possible to make up for it to some extent by a careful return of crop residues and manure. It is estimated that another 2,000,000 tons a year is lost by erosion, much of which could be prevented. Lack of phosphorus may sometimes be the most decisive factor in causing erosion because it results in poor stands of plants.

But the problem is not simply one of phosphorus as such. The combinations in which this element exists in the soil are extremely important. Only a small part of the total amount present at any one time is in forms that can be used by plants; the rest is locked up in chemical compounds that plants cannot use (though there are differences in plants in this respect). Ordinarily, however, these un-

available compounds do slowly change to others that are available. In general, phosphorus combined with calcium or magnesium is most readily available and that combined with organic matter next. Phosphorus combined with iron or aluminum is relatively unavailable, and that present in rock is the least available of all.

Superphosphate fertilizers are readily available compounds of calcium and phosphorus. Adding calcium to acid soils in the form of lime decreases acidity and makes the soil a better medium for the plant to obtain phosphorus. It is thought that in southern soils, and perhaps in all acid soils, the proportion of phosphorus in the form of unavailable iron and aluminum compounds is comparatively high, so that these soils respond especially well to additions of phosphorus in more available forms.

The fact that so much phosphorus is in unavailable forms has one advantage—it conserves the supply and makes the effects of phosphorus applications last over several years as the compounds slowly change. In fact, with very heavy applications in intensive farming it is apparently possible to build up an actual reserve.

The practice of top dressing pastures with phosphates is receiving more and more attention today as it is realized that this element is just as important for pasture plants as for crop plants. Legumes especially need an ample supply.

An adequate supply of available potassium improves the quality of plants, assists in the functioning of chlorophyll, increases resistance to certain diseases, offsets the effect of an oversupply of nitrogen, helps the plant to utilize soil moisture more advantageously, and in the case of grains insures well-filled kernels and stiff straw. A deficiency is quickly evident in marked reduction in yield and, with some crops, in various symptoms of potash hunger. Cotton and tobacco have the greatest need for potassium, and a large percentage of the potash fertilizers used in the United States are applied to these crops. Potatoes, sweetpotatoes, sugar beets, certain cereals, and truck crops also need relatively large amounts.

All soils contain potassium, and compared with nitrogen and phosphorus the quantity is high except in sands, some light sandy loams, muck, and peat. Generally, however, the potassium is present in relatively insoluble compounds. Moreover it is essential to maintain the supply in the soil because most crop plants remove rather large quantities every year. In the Southeast, leaching has reduced the supply of available potash to a comparatively low point.

Although potassium is widely distributed in the earth's surface, large accumulations suitable for fertilizer purposes were confined mostly to France and Germany. Recently, large underground deposits have been found in the United States, chiefly in the Southwest.

The Use of Rotations and Organic Materials

It will be evident from the discussion so far that in general nothing is more vital to good soil management than providing for the regular and systematic return of organic matter to the soil. Several practices help to accomplish this, and all of them do other desirable things as well.

By and large, rotation of crops, including the use of grasses and legumes in the rotation, is probably the most important. It does

several things at once. It gives diversification so that all the farmer's eggs are not in one basket. It helps to keep the soil in good physical condition, which means good tilth and better water-storage capacity. It improves fertility by providing organic matter, especially when crops are turned under, and also nitrogen if legumes are used. It provides roughage and pasture for livestock, with a consequent return in manure. It helps to make possible the most effective use of fertilizers. It helps to prevent erosion by keeping the land occupied with crops, and by keeping cultivated crops off sloping land part of the time. It changes the location of the feeding range of roots by alternating shallow-rooted and deep-rooted plants, which tends to distribute plant nutrients through the soil and prevent local exhaustion of the supply. It is a very important factor in the control of most weeds and helps to control some plant diseases and insects. And finally, it improves the quality of some crops, notably grains.

Broadly, the three types of crops, from the rotation standpoint, are grass and legumes, grains, and intertilled or row crops. It would be well if intertilled crops could always be thought of as soil-depleting—necessary, but to be kept under control, like an automobile, which is always potentially dangerous in addition to being useful. Grass and legumes are like the brakes on an automobile. The steeper the hill, the more necessary it is to have good brakes; but they are also needed on the level.

What particular system of rotation will be used on a given farm depends on regional and local conditions and on the farmer's own needs. The relief or slope of the land is a decisive factor. So is the climate, the soil, the type of farming, the seasonal distribution of labor, the market situation. In any case, the rotation system should be based on a long-time plan, with plenty of knowledge back of it. But there need be no stiff-necked adherence to the same plan forever. It is often advantageous to make changes. There are broad differences between the crop rotations used in the Corn Belt, the Cotton Belt, the Dairy Belt, the Wheat Belt, the dry-land area, and the irrigated sections. The actual practices could be improved in many cases.

The two types of cover and green-manure crops—legumes and nonlegumes—behave quite differently and have different functions. Nonlegumes—rye and buckwheat, for example—furnish the larger amount of organic matter, but they may actually reduce the supply of nitrogen in the soil during decay, especially if they are plowed under when no longer young. Legumes, on the other hand, add nitrogen, which is taken out of the air by the bacteria on their roots. In the South, however, this nitrogen may be lost from the soil before the next crop is planted unless a nonlegume follows immediately. Even in the Atlantic and Gulf Coast States, where legumes are most generally used, large areas are left bare that could be advantageously covered with these crops. In the South there is room for vast improvement in this respect.

Manure should be included among the organic-matter additions to the soil rather than the fertilizers, because, although its fertilizer content is valuable, its chief benefits come from adding humus and improving tilth, water-holding capacity, aeration, temperature relations, and the activity of micro-organisms. The billion tons of manure

produced annually on farms in the United States contains twice the amount of organic matter annually removed in the grain and cotton crops combined. If it could all be used without loss, it would produce crop increases worth many millions of dollars. But probably only one-fourth to one-third of its potential value is now realized. Half of it is dropped on pastures and uncultivated ground. From the part handled as manure, there are heavy losses, some of which could be prevented by proper handling.

Several practical rules apply. The liquid portion should be saved as much as possible—for example, by the use of clay or concrete floors. The manure pile need not be covered, but if it is not, it should be high and narrow and perhaps protected on the sides. Above all, it should be well compacted to exclude air; the easiest way of doing this is to let the animals tread it down. The addition of superphosphate has much to recommend it. The litter used is a decided factor in the quality of the manure. The manure should preferably not be held in storage over the summer because it deteriorates more rapidly in hot weather. Lighter applications, supplemented with commercial fertilizers, are in general more economical than heavy applications. It should be applied to crops of high acre value, but it may often be used advantageously on worn-out land, and top dressing to improve the stand of grasses and legumes is worth while. The best incentive to the proper handling of manure is an understanding of its true nature, the perishable character of its valuable constituents, and the direct money loss that results from improper handling.

Although the use of organic amendments other than manure is seldom practiced in general farming or on extensive areas, it often has considerable value for specialized conditions, as in greenhouses, vegetable and flower gardens, and lawns, and for cuttings and seedlings. Many plant wastes may be used in this way, especially if they are composted in a heap with the addition of fertilizers and regular watering to hasten decay and prevent undue heating. One widespread use of some of these materials is to create an acid soil condition for acid-loving plants.

The Use of Fertilizers and Lime

To determine what fertilizer treatment a soil needs—and also the results of various practices besides the application of fertilizers—three experimental methods are in use: Laboratory tests (including the so-called quick tests) involving the use of chemicals or biological methods; pot tests with field crops or selected test crops; and plot tests in the field.

Laboratory tests with chemicals have recently been attracting widespread attention. In general, they consist in adding a definite volume of soil to a definite volume of an extracting solution for a definite short period, and then filtering the mixture or allowing it to settle. The color or the cloudiness produced, when compared with a chart or other measuring device, indicates the amount of a given fertilizer element in the soil, or the amount needed. In the hands of an experienced agriculturist who knows the soils of the locality and can take other factors into account, such tests may give useful in-

formation, especially if they are expressed in broad terms rather than quantitative figures. Different tests must be used for different soils and different regions, however; there are many complicating factors; and the method must still be regarded as supplementary and by no means uniformly certain.

Pot tests involve the growing of plants in samples of soil, in the greenhouse or elsewhere. All factors are kept uniform except the one being investigated, which is varied, under close control, to show the effects of different treatments. This method is especially useful to determine the value of different compounds of a fertilizer material, or to detect the absence or overabundance of a certain element in the soil.

In field-plot tests, which have been used the longest, such accurate control is not possible. On the other hand, conditions are more like those in actual farming, and economic results can be evaluated more truly. Much of our present knowledge of the value of rotations and many other practices has come from long-continued plot tests, which are carried on at most of the State agricultural experiment stations.

So far as the three chief fertilizer materials—nitrogen, phosphorus, and potassium—are concerned, the situation in the United States has changed remarkably since the World War. The need for an independent supply of nitrogen for explosives forced the development of commercial methods of separating nitrogen from the atmosphere, combining it with other elements, and producing stable compounds. After the war, plants manufacturing explosives turned to the manufacture of fertilizer materials. Potash production in the United States has also developed rapidly since the war cut off the supply from Germany; in 1935 the United States produced 50 percent of its potash fertilizer needs compared with 9 percent in 1923. In phosphorus production this country has long been independent, but there is need to use the supply wisely.

Whereas in 1900 fertilizer nitrogen came mostly from organic compounds, today it comes mostly from inorganic compounds. The list of nitrogen and phosphorus compounds is very much longer now than it was then. Moreover, the modern trend has been toward higher and higher concentrations, for economy in manufacture, handling, and transport.

Nitrogenous fertilizer materials are classified according to the way the nitrogen is combined. There are four groups:

(1) Those with nitrogen in the nitrate form—sodium nitrate, for example. These are readily soluble, quickly utilized by plants, but also readily leached from the soil.

(2) Those with nitrogen in the form of ammonia or its compounds—sulphate of ammonia, for example. These are soluble but less readily leached.

(3) Those with nitrogen in the form of organic ammoniates—tankage and cottonseed meal, for example. These are complex protein compounds, mostly insoluble unless changed by special treatments—as in steam-treated tankage—but slowly converted by decay.

(4) Those with nitrogen in the amide form—urea and calcium cyanamide, for example. These are carbon compounds, like organic matter, but not protein. They are mostly soluble in water and usually quickly changed by bacteria to ammonia and nitrates.

Of the considerable list of nitrogenous fertilizer materials, sodium nitrate and ammonium sulphate are the two most widely used today.

Phosphatic materials are not so neatly classified, but they also contain phosphorus in different forms, and availability is the big factor in determining their fertilizer value. Some, for example ammonium phosphate, contain phosphoric acid entirely or mostly in a water-soluble state. The principal materials now used in the United States are superphosphate with 16 to 20 percent of available phosphoric acid; treble superphosphate with 40 to 48 percent; ammonium phosphate—which increases soil acidity—with 48 percent plus 11 percent of nitrogen; bonemeal, which is high in lime, with phosphoric acid only slowly made available; basic slag—a byproduct of the Bessemer process of manufacturing steel—which is not used in fertilizer mixtures but is useful by itself on heavy and lime-deficient soils; and finely ground rock phosphate, which is also used for direct applications rather than in mixtures.

In potassic fertilizer materials, all the potash is water-soluble and readily absorbed by plants. The potash content ranges from 47 to 61 percent in potassium chloride (muriate of potash) down to 1.5 to 8 percent in hardwood ashes.

Of other fertilizer elements not ordinarily considered, calcium and sulphur are contained in some common fertilizer materials, but they are completely lacking in others. Magnesium, in the form of calcined kieserite, is now added to some materials by some manufacturers for magnesium-deficient soils.

Since farmers in the United States spend over $200,000,000 a year for fertilizers, it pays to study the advantages and disadvantages of the many different materials available. Nearly 70 percent of the fertilizers used in this country, however, are already mixed, most of them containing all three of the principal fertilizer elements.

Several major advances have affected mixed fertilizers in recent years. One of the most important has been the treatment of superphosphate with free ammonia to make ammoniated superphosphate, a nitrogen-phosphorus fertilizer. Among other advantages, such a mixture provides a cheaper form of nitrogen than did the old mixture of fish scrap or other organic nitrogen products with bone superphosphate, and it has better mechanical and storage qualities.

The efficiency of a fertilizer mixture depends on two things—the uniformity with which it can be distributed and its effect on plants. The first is a matter of physical condition, the second of chemical composition. Fertilizer cannot be distributed evenly if it tends to cake or if the particles are of different sizes so that they segregate. Methods have been developed to overcome these tendencies. One of the principal considerations in the application of fertilizers is that of preventing "burning" of the plant. This occurs when the concentration of salts in the soil solution becomes so great that the plant is prevented from absorbing moisture through its roots. It then dies. The difficulty has been partly corrected by the use of high-analysis mixtures, so that less fertilizer is applied to the soil, and by replacing kainite and low-grade potash salts with high-grade muriate. (The method of applying fertilizers is also important from this standpoint.)

The reaction of fertilizer materials is another important matter. Before 1906, the fertilizer materials in general use produced mixtures with an alkaline reaction. As new materials came into use, the reac-

tion became less and less alkaline until in 1906 it was neutral. After 1906, other new materials made the mixtures steadily more acid. In the long run, these fertilizers would build up the acidity of soils. Since 1932, however, mixtures have been neutralized by adding the proper amount of limestone or, preferably, dolomite.

Since 1900 the f. o. b. price of fertilizer materials except organic ammoniates has been reduced 50 percent. There has also been a steady tendency to use higher analysis mixtures for reasons of economy. Calculations made in 1934 showed that by eliminating the 400 pounds per ton of sand filler in a 4–8–4 mixture, which would automatically make it a 5–10–5 mixture, the farmer could save 12½ percent of his fertilizer bill. By using a 6–16–6 mixture instead of a 3–8–3, he could save 25 percent of his bill. It is no longer economical to use such mixtures as 3–8–3, 2–9–3, 0–10–4, and 2–8–2, which have less than 16 percent of total nitrogen, phosphoric acid, and potash.

Other savings may be brought about by the method of applying fertilizers. It is only within the past few years that soil investigators have considered this question, and many farmers still do not realize the importance of proper placement. A recent cooperative experimental program with public and private agencies has brought new facts to light.

Briefly, the experimental work indicates the decided superiority of band placement for row crops over the old method of broadcasting. The concentration of nutrients close to the young plant by the band method favors early growth and maturity, which has many advantages (except in special cases, including summer drought); and a smaller proportion of the fertilizer elements is fixed in unavailable forms by the soil, which makes for economy. The best pattern for most conditions has proved to be side bands rather than bands directly above or below the seed or mixed with it. The bands may vary from ¾ to 2 or more inches in width and be placed from ¾ to 2½ inches away from the seed, depending on the rate of application, the sensitiveness of the plant to fertilizer injury, and the texture of the soil. In general, it is best to have them at or a little below the level of the seed. New machines have been developed for placing fertilizers in accordance with these principles, and in many cases it would pay farmers to replace obsolete machinery. Enough experimental work has been done with several specific crops to make definite recommendations possible for fertilizer placement.

Lime is not ordinarily a fertilizer material, but for practical purposes it may be considered along with fertilizers. The practice of using it is ancient, but it has lagged in this country, partly because adequate methods for determining lime needs and knowledge of its proper use have not been available until recent times.

In general, lime is needed in all humid regions, where leaching prevents the accumulation of lime carbonate in the soil. It may be considered the backbone of good crop production and soil conservation in these regions. The aim should be, first, to use enough lime to bring the soil reaction to the proper point, and thereafter to apply enough to balance the amount lost each year by leaching, over and above what is returned by manure and crop residues. In the North Central States, this annual loss, in terms of lime carbonate, amounts to 100

to 500 pounds per acre per year. Thus 2 tons of ground limestone per acre would in general balance the net loss for a period of 10 to 20 years. Taking Wisconsin as an example, an initial application of 15,000,000 tons of ground limestone would be required to bring the soil up to a satisfactory lime level throughout the State. Thereafter it would take about 1,000,000 tons a year to maintain the level. The cost per acre would be small, especially when compared to the increased production and the soil improvement that would result.

Yet figures on the use of lime throughout the humid part of the United States show that in no State is the lime budget balanced. The experience of Wisconsin is significant in indicating the reason for this. The use of lime was low in that State until 1934, when the mining and grinding of limestone materials was undertaken by work-relief programs. With cheap lime available, farmers immediately began to use five or six times as much as they had before.

On a particular farm, the lime needs of each field, and even parts of fields, should be determined by the use of a soil-testing kit. This will indicate the amount needed to bring the soil up to the desired reaction, which varies somewhat for different crops. Then a soil-acidity map of the farm should be made for future guidance.

Soil reaction has both direct and indirect influences on the growth of plants. The indirect influences include effects on the physical condition of the soil, the availability of essential elements, the activity of soil micro-organisms, the solubility and potency of agents poisonous to plants, the prevalence of plant diseases, and the ability of some plants to compete with others. The direct effects include the poisoning or destruction of plant tissues (in extreme cases of acidity or alkalinity), and an unfavorable balance between acid and base elements available for absorption by plants. It is only in recent times that these effects have been understood, and there is much research still to be done.

Erosion Control

The normal geologic erosion that has gone on for ages under natural conditions is a part of the whole complex soil-making process. But when man steps in and cultivates the land, he creates conditions that may result in an enormous acceleration of erosion. Under certain circumstances, this accelerated erosion is the most dramatic and disastrous of the evil things that can happen to the soil.

It is of two familiar types, water erosion and wind erosion. Water erosion occurs chiefly on sloping land, removing the soil in sheets (sheet erosion), or cutting it with many small streamlets (rill erosion), or gashing out deep gullies (gully erosion). The steepness of the slope, the soil type, the intensity of rainfall, and the land use all affect the character and the rapidity of this process. Wind erosion occurs on both sloping and level land, and it too is affected by soil type. One factor is common to both kinds of accelerated erosion—they depend on removal of the natural vegetative cover, which includes its complex of underground roots and its residue of organic matter on and in the soil. For example, some experiments show that a cover of dense vegetation is 300 times more effective in holding soil and 6 times more effective in retaining rainfall than clean-tilled crops on the same kind

of land. Moreover, the rate of erosion increases as the upper layers of soil are successively removed.

In the United States, agriculture has steadily progressed and expanded, but it has left a heavy toll of erosion, which has been summarized in previous pages.

It is very clear today that no single remedy is adequate to control this destructive process. There must first of all be a widespread understanding of the problem on the part of farmers and the Nation as a whole; then planned research to uncover facts not yet understood, demonstrations of sound soil management to serve as guides, adequate methods of cooperation among farmers and between farmers and public agencies, alleviation or removal of economic pressures that make it difficult for individuals to change practices that damage the land, and practical coordination of all these steps.

As for the erosion-control practices themselves, they may be illustrated by the steps taken in an actual demonstration conducted on about 30,000 acres in Texas. On each farm in the demonstration area several of the following practices were combined according to the need and the situation: Strip cropping, terracing of slopes up to 5 percent, crop rotation, use of cover crops, retirement of severely eroded land to grass or trees, contour cultivation, planting of critically erodible areas to feed and cover plants for wildlife, control of gullies chiefly with grass, control of terrace outlets with grass, construction of small grassed channelways to carry water discharge safely downhill, establishment of meadow strips, pasture development by contour furrowing and reseeding, pasture improvement through rotated grazing and other practices, recombination of fields to achieve a better lay-out, construction of small reservoirs for stock water, planting of black locust to protect certain slopes, and field stripping to prevent wind erosion.

In regions where there is sufficient rainfall—which includes nearly half the United States—forests must be considered the first line of defense against erosion where permanent and certain protection is required, on steep slopes, on deep erodible soils subject to gullying, on land eroded down to sterile subsoil, and on abandoned farm land permanently released from cultivation. The removal of forests is in itself responsible for accelerated erosion in many areas. Their effectiveness for control is amply proved. To take a single example among many: During a storm in northern Mississippi, land under forest cover lost 75 pounds of soil per acre. Nearby land under cultivation lost 68,000 pounds per acre.

It is not primarily the network of tree roots that makes forests so effective in holding soil, as most people think, but the forest litter—the carpet of dead leaves, twigs, limbs, and logs. This helps to make the soil porous, and it prevents rain from hitting the ground with an impact hard enough to dislodge silt and clay particles. Once dislodged, these particles close the tiny pores and channels in the soil, which forces the water to run off the unprotected surface instead of soaking in. When fires and overgrazing destroy this forest litter, they largely destroy the effectiveness of forests for erosion control.

Fifty million acres of farm land have already been abandoned by farmers because they are no longer productive, and 30,000,000 acres more are in process of abandonment. Fully 11,000,000 acres of this

total will not revegetate naturally and should be reforested. On perhaps another 10,000,000 acres revegetation will be slow, and planting trees would hasten the process. In the case of abandoned land, reforestation is up to the public, since it would not pay private initiative; and that means that the land should be acquired by the public. But on some 8,000,000 acres of submarginal land still included in farms that are going concerns, reforestation—which may often be in the form of farm wood lots—should be largely in private hands, with Government advice and assistance. Although the rate of reforestation for erosion control has been greatly accelerated within the past few years, it is not anywhere near keeping pace with the rapidly increasing need.

The use of grass and other close-growing vegetation is the other great natural method of controlling erosion and conserving water. It is practicable where forests are not, whether because of climate or for practical farming reasons. Moreover, just as stripping away the forests has resulted in erosion, so has reducing the grass cover. The remedy in both cases is to get back to nature's methods of erosion control. This does not mean turning the country over to grass and trees. It means fitting nature's methods in with regular farming operations.

Grass need not be stripped off to produce accelerated erosion. It need only be affected to the extent that the best perennial grasses are reduced or ruined and replaced by inferior annual grasses and weeds. It is common knowledge that this has happened over very extensive areas, especially where there has been overgrazing. But overgrazing can be remedied by two simple means—increasing the number of acres per head of stock and rotating pastures. There is ample evidence, based on long-time studies, that both practices pay in more rapid and larger gain in weight of livestock, which means better market prices; in larger calf crops; and above all in range and pasture conservation, especially during periods of drought.

The practical uses of close-growing grasses, legumes, and other plants on the farm are many. They fit into rotations. They may be used for grassed waterways, buffer strips on sloping land, terrace outlets, and control of gullies. Land not needed at the moment may be seeded to grass. In such cases the thick-growing vegetation frequently furnishes food for livestock as well as improving the soil and controlling erosion. In the case of pasture improvement, fertilizer, lime, and reseeding may be essential. Recent investigations are resulting in worth-while new developments in the use of this kind of cover. Practically every commercially available grass and legume and many herbs and shrubs have been used on farms in erosion-control projects, and many others, collected from all over the United States and abroad, are being tested.

Contour furrowing, or plowing and planting land across the slope instead of running the furrows up and down hill, has long been practiced by intelligent farmers. It is now being carried a step further by planting the land in alternate strips of close-growing and cultivated crops. Strip cropping has proved to be one of the simplest, most widely useful, most effective, and most inexpensive methods of controlling erosion. There are three types. In contour strip cropping the true

contour of the land, including all its irregularities, is followed closely, with not more than a 2-percent deviation in any 100 feet. In field strip cropping, the strips are across the general slope, but the contour is not followed closely. In wind strip cropping the strips are at right angles to the direction of the prevailing winds, irrespective of the contour of the land. Field strip cropping is not as effective as contour strip cropping, but it may be justified in some cases provided low areas and depressions, where the strips are thrown off contour and collect water, are kept as permanent grassed waterways. Wind strip cropping is applicable only to limited areas. It does not conserve water, and contour strips may be preferable in any given case because the water conservation they furnish will give a better growth of vegetation.

What is required in putting strip cropping into effect is courage to change the farm lay-out and to some extent the cropping system. The method can be fitted in perfectly with rotations, however, since strips can be rotated just as easily as the more conventional fields. After the decision is made, the laying out of strips is not especially difficult, although it requires careful consideration of several different factors. A million acres are now strip-cropped in soil conservation demonstration projects throughout the country, and farmers interested can get much information by visiting one of these projects.

Strip cropping is only one of the vegetative methods of erosion control. There are also several methods that may be called mechanical rather than vegetative. Many or most mechanical measures can be put into effect by farmers with ordinary tools, or with special machinery cooperatively purchased. They are being incorporated more and more into regular soil-management programs. Often, however, there is need for preliminary advice by the technician in estimating the quantities of water to be handled and the forces involved. The three ends to be achieved, always, are surface protection by vegetative covering, absorption of the maximum quantity of water by the soil, and the movement of any large concentrations of water from steep areas through protected channels.

One of the simplest of the mechanical control devices consists of shallow ditches or diversion channels running across the slope. These conduct water off at a low velocity so that it does not erode as it flows. A drainage-type terrace is practically such a channel, supplemented by a low ridge on the lower side, following the grade. An absorption terrace consists of a ridge with little or no grade; it does not conduct the water off but holds it on the land above the terrace until all of it soaks into the soil. In the semiarid dry-farming region, level terraces are sometimes used for this purpose. Bench terraces, which look like a series of steps, are used only on very steep land. They are expensive to construct and are justified only under exceptional conditions.

Terracing may sometimes be worth while on new pasture land as well as cropland, and on established pastures the use of contour furrows or ridges at intervals, and of diversion channels, may be highly advantageous or necessary. On the range, practical conservation devices include, in addition to proper range management, reservoirs or stock tanks formed by impounding dams on small contributing watersheds; water spreading by contour furrows, ridges, and dikes; and flood irrigation by damming gullies to divert water across wide flat valleys.

All channels conducting water must themselves be protected from erosion. Minor channels of low velocity may often consist of grassed meadow strips following a natural drainageway. If they are of high velocity, on steep grades, channels must be lined with concrete or some other material. Major channels often require dams, so that ponds may be formed or the channel level raised. Temporary dams of brush, logs, or rock may be used to stabilize the flow line of gullies until vegetation is established. Gully control is also greatly simplified by diverting water away from the gully by ditches or terraces.

Reducing wind erosion depends on setting up obstructions that will slow down velocity and on increasing the size of the soil aggregates—as by a lumpy surface—so that the wind cannot readily pick them up. Among the obstructions are lister ridges, clods, and stubble. Permanent wind-erosion control, however, must center around the maintenance of a favorable soil condition, usually involving a good vegetative cover.

The fact that no single method can be relied on to control erosion on a given farm or in a given area has already been stressed. In the South, for example, many people formerly thought terracing was almost all that was needed. Terraces alone could not do the job, quite aside from the fact that many of them were wrongly constructed. Today agricultural scientists are working toward a much broader approach and trying to take all factors into account.

But many questions remain to be answered. In parts of the ary areas of the West, restricted and well-managed grazing will go far toward restoring the grass cover, except where destruction has proceeded so far that mechanical structures are needed in addition. In the cultivated areas of the dry region the problem is much more complex. For one thing, a decision must be made on the fundamental question of whether the continuous use of land under a wheat-fallow system can be considered feasible as a permanent type of agriculture in a country where the balance between moisture conditions and crop production is so delicate. If not, what other system is possible? In the humid South, where erosion has been severe, basic revisions in the farming system will sometimes be necessary to make room for the combination of practices required to cure the sickness of the soil. In the Corn Belt, erosion has not progressed so far and there is an opportunity to work out a sound preventive program, with more conservative practices worked into the regular farming system. Within these regions each farm presents its own individual problems, practically field by field. The best way for a farmer to see what can be done is to study what is being done on demonstration farms where investigations are being made and remedies applied in detail.

Some Special Areas and Problems

Dry farming, irrigation farming, and the management of forest soils present peculiar problems that call for separate treatment.

Marbut pointed out that, because they have been subjected to a minimum of leaching, dry-land soils are exceptionally rich in plant nutrients, and the thickness of the fertility layer may often be measured in feet where in humid forest soils it is measured in inches. This is both the value and the danger of the semiarid soils. Crop

returns are so heavy in years of ample rainfall that production is expanded. A succession of years of low rainfall then leads to ruin. The primary lesson that must be learned in dry farming is that only the long-time average has any meaning in measuring returns.

Except in certain areas, the moisture content of the soil is the sole factor controlling failure or success in crop production, with wind erosion quite commonly and water erosion occasionally as complicating elements. This means that all dry-farming operations center around the moisture supply. Several fallacies about soil moisture have been exploded by the experimental work of the past 20 years, though some farmers still believe them. Four facts are basic.

(1) Crop yields are not directly proportional to the amount of available water in the soil. They depend on the amount available over and above the minimum required for any crop at all. If 10 inches of rainfall is required for any crop, 9 inches will mean total failure; 12 inches, or 2 inches over the minimum, will mean a small crop; 14 inches, or 4 inches over the minimum, may give twice as much yield as 12 inches.

(2) Precipitation is the sole source of water supply except in special areas; water will not come magically from some imaginary water table or elsewhere.

(3) Small-grain crops normally use all the available water, leaving the soil dry at harvest time.

(4) There are only three fundamental ways of increasing or making the most of the available water supply—increasing the absorption of water by the soil, as by tillage practices, the use of stubble, and level terracing to reduce run-off; saving up the water in the soil one year for use the next year or two, as by leaving the land idle, in fallow; and preventing undue withdrawal of water, as by killing all weeds and using water-conserving crops.

But the semiarid areas are by no means uniform, and how these basic facts are used to guide farm practice depends on all the conditions in a given locality.

Irrigation has developed most completely and extensively in the arid sections. The irrigation pioneers in this country were the Indians of the Southwest, before the coming of the white man; the Spaniards; and the Mormons, who established community enterprises in Utah and elsewhere. Subsequent developments were varied. They included many privately owned irrigation systems, as well as mutual irrigation companies, public-utility companies supplying water for profit, the establishment of public irrigation districts, and the reclamation movement following the Reclamation Act of 1912.

Partly as a result of this diverse growth, irrigation presents some complex financial and legal problems, the latter concerned especially with water rights. There are also many physical problems, on some of which there is need for further research. The physics of soil moisture and soil-moisture-plant relationships are two fields for fundamental investigation. The possibilities of supplemental irrigation to provide feed for livestock and to extend home gardening in dry areas are promising, but they need study from an economic standpoint. There are practical rules for the application of irrigation water, but much could probably be done to make this more efficient. There is need to perfect and extend a system of land classification to determine the suitability of land for irrigation. The need for determining in advance the prospective water supply from various watersheds led to the establishment of regular snow surveys. These have been very useful, since much irrigation water comes from melted snow.

Failures in irrigation agriculture have not been uncommon, and they are likely to be exceptionally costly. A review of their history shows that for the most part they have been due to unfavorable conditions of soil, water supply, and drainage not realized before development was started. This emphasizes the necessity of adequate analysis of these factors in advance. Although the task is technically difficult and more fundamental information is needed at many points, enough experience has accumulated by now to make it possible to avoid many costly mistakes.

Primary consideration must always be given to the soil solution, which in turn is influenced by the quality of the irrigation water. Unlike rain water, irrigation water contains dissolved substances, often in considerable quantities. These may accumulate in the soil—which in fact may already contain a large amount of salts before it is irrigated—and in time produce profound changes that result in declining crop yields. Usually the changes are unnoticed in the beginning; by the time the injury becomes obvious, they have gone so far that remedies are expensive, difficult, and slow in operation. The causes and the nature of these changes are complex matters of soil chemistry and physics. In general, they are of two kinds—overconcentration of the soil solution, which directly damages plants, and deterioration in the physical properties of the soil mass.

One change to be particularly feared is an increase in the proportion of sodium as compared to calcium and magnesium. Through the phenomenon known as base exchange, this may lead to dispersion of the soil particles, a tough or rubbery condition of the soil mass, and impaired tilth and permeability. A possible corrective measure is the artificial application of calcium. It is of first importance, however, to have or to provide good drainage conditions so that too high concentrations of harmful salts can be flushed out of the soil by the use of excess water. Bringing water to the soil seems to be the principal problem in irrigation agriculture, but getting it out of the soil again is just as vital.

Artificial drainage is of course a common practice in the humid regions not only to remedy wet spots in fields but more extensively as a form of crop insurance. Cold, wet soils are late to warm in spring and subject to early frost and severe winter heaving, and drainage is necessary if they are to be developed satisfactorily. On the other hand, in many cases the cost of drains may be several times what the land is worth. In the case of peat and muck especially, the profitableness of drainage is often extremely doubtful, particularly when it is considered that these soils are a fire hazard when dried out.

Open drains have a limited usefulness in general farming. Underdrains of tile are permanent and efficient, although much money can be spent on them with unsatisfactory results if the system is not properly designed and constructed. In general, the drainage systems are of two types—those with long parallel laterals, uniform in depth and spacing, for fairly level land; and those with side lines to intercept seepage on hillsides. Depth and spacing are determined by the character of the soil and the crop; the general design is determined by cost, available outlets, grades, and source of water. Tile lines should

be as straight as possible, with easy curves. There should be no spaces between tiles, which should be laid carefully on a firm ditch bottom. The tile should be dense and durable rather than porous, and ring when struck. Mole drains, made by a steel ball or bell dragged through the soil below the surface to form a round, unlined channel, seem to have given good results in Europe and are being studied in this country.

The management of forest soils is a problem that up to the present has received little or no attention in this country. The principles that should be followed are just beginning to be understood. The main points are: To maintain the forest litter so that it is not depleted faster than it accumulates; to use mixed stands of trees, which is the forest equivalent of rotation of crops; and to use the best types of trees adapted to the particular soil—in general, hardwoods wherever possible, since hardwoods return larger quantities of nutrients to the soil than conifers. Applying these principles means restricted cutting to maintain full stands, prevention of fires, and control of grazing. In the West, where grazing land is intimately mixed with the forest, control consists in limiting numbers of livestock to the actual carrying capacity of the forage. In the East, where grazing land and forest are not commonly mixed, it is probably much better to keep stock out of the forest altogether and to clear areas for pasture if it is needed. Studies in Wisconsin show that soil losses were nearly 100 times greater and water losses 60 times greater from a pastured than from an unpastured wood lot.

Soil and Plant Relationships

In all soil management, the important point obviously is the relationship between the soil and the plants that grow in it. With due regard for economic factors such as accessibility to markets, good management consists (1) in selecting the right plants for a given soil, or in choosing the right soil for a given plant; (2) in maintaining the soil so that it remains suitable for the plant; or (3) in modifying it so that it is more suitable.

If a soil is to be favorable for the growth of crops, it must meet six fundamental conditions, some of which can be brought about to a considerable extent by management practices:

(1) It must be suited to the use of efficient cultural implements.

(2) It must offer effective resistance to destructive erosion or depletion under a desirable cropping sytem. Certain silt loams and very fine sandy loams, for example, are excellent for plants but so subject to erosion that they cannot be used for certain crops for any length of time.

(3) It must be capable of storing enough moisture to meet crop requirements under normal rainfall or irrigation. Texture, structure, and depth to the water table are important factors. The first two, at least, can be modified by proper management.

(4) There must be adequate aeration to permit the development of a good root system. Where this is lacking it can often be provided by drainage; but in heavy, impervious soils or where the water table is near the surface, satisfactory drainage may be impossible.

(5) There must be a supply of plant nutrients sufficient for profitable yields. Here management can be profoundly effective in altering infertile soils by the use of fertilizers, cover crops, and manures.

(6) The soil must be free of unfavorable chemical conditions such as excessive acidity or alkalinity, harmful concentrations of salts, or excesses of certain elements

that create an unbalanced condition for plants. Here also good management may often correct defects, as by the use of lime to bring about the most favorable soil reaction.

Most of these points, it will be noticed, have to do with the needs of the plant for water, oxygen, and nutrients. The success attained in growing plants in water cultures, without any soil whatever, shows that these are the three things on which attention must be centered.

Within these broad requirements, there are certain most-favorable soil conditions for the growth of particular crops. The Hagerstown silt loam of the Appalachian limestone valleys, for example, will grow almost any temperate-zone crop satisfactorily; yet corn will do better on other soils, and so will some of the market vegetables, and so will fruit. These most-favorable conditions, existing naturally, have largely determined the areas specializing in various crops, and they should be understood as one of the principal elements in successful production.

Certain interesting aspects of this matter of soil-plant relationships have received attention only in comparatively recent years. One of these is the question of the effect of soil composition on plant composition and functioning.

All animals, including man, get their nourishment ultimately from the soil. The plant serves as the intermediary, drawing chemicals out of the soil into its sap and changing them into compounds that can be used by animals for building flesh, blood, and bones. But if the soil is deficient in one or more of the necessary elements, plants may be unable to get enough of it to supply the needs of the animal. This is notably true of phosphorus in several areas in the United States and elsewhere. Animals feeding on plants in these areas are subnormal in development and even subject to severe diseases.

The whole subject of the effect of soil composition on plant composition, and through this on animal health, deserves the increasing attention it is getting today. It is complicated by the fact that the elements originally in the soil are by no means the only factors in determining what the plant will contain. Continuous cropping, for example, changes the picture by depleting the soil of some elements, and plants react accordingly. Again, experimental evidence shows that different varieties of the same plant grown on the same soil may contain different proportions of some elements; there are selective forces at work in addition to the composition of the soil itself. The period of growth of the plant makes a difference in its composition; cuttings of alfalfa, for example, taken at different stages of growth, have been found not to have the same content of calcium and phosphorus.

Climate, including temperature, rainfall, and sunshine, also affects plant composition. Investigators in Kansas, California, and Maryland once exchanged samples of soil and grew the same wheat in the same soil under different climatic conditions, with marked effects on the content of protein, mineral ash, phosphoric acid, and potash. Water supply is another factor. In general, more minerals are absorbed by the plant as the water supply increases; grain grown on irrigated soils has a higher mineral content and a lower protein content than that grown without irrigation, and it has been suggested that

the differences are great enough to be useful in animal feeding. Finally, the use of fertilizers makes a difference. Within limits the content of certain elements in the plant can be increased or decreased by manipulating fertilizer formulas—though comparatively little is known about this, and there are many conflicting statements. As a guide to corrective measures where there is either a deficiency or an excess of some element, attempts have been made with some success to diagnose the nutritive condition of plants by chemical analysis of selected leaves or by an examination of their color, form, and other visible characteristics.

The major elements are not the only ones that are important from this standpoint. Iron and boron are now included among the elements necessary for normal plant development. Early in the twentieth century, manganese, copper, and zinc were added to the list, and a few years ago nickel and cobalt were tentatively added. Only very small concentrations or traces of these so-called secondary elements—a few parts in a million parts of soil—are needed, but without them the plant suffers. Too great a concentration, on the other hand, may be harmful or fatal; this has been found to be true in the case of boron. Some other elements poisonous to plants or animals at relatively low concentrations are aluminum, arsenic, barium, chromium, fluorine, lead, selenium, and thallium.

Discoveries in this field have led to remarkable results in clearing up the causes of certain mysterious diseases of plants. Sand drown of tobacco has been found to be due to a deficiency of magnesium in the soil; chlorosis of tomatoes on certain Florida soils to a deficiency of manganese; pecan rosette and citrus leaf mottle to a deficiency of zinc; internal cork of apples, top rot of tobacco, cracked stem of celery, internal browning of cauliflower, and dry rot of sugar beets to a deficiency of boron; wilting of the upper leaves of tobacco to a deficiency of copper. Again, a deficiency of iron and copper, and possibly cobalt, in sandy Florida soils affects the development of cattle feeding on plants from these soils. Lack of cobalt in certain New Zealand soils causes the "bush sickness" of sheep.

Large crops grown on highly cultivated soils, without replacement or return of residues, deplete the natural reserves of these elements. The use of commercial fertilizers consisting of almost pure salts may hasten this process through the complicated reactions of base exchange, which make some secondary elements more rapidly available for use by plants. The return of organic matter to the soil, and the use of stable manure, tend to conserve them. Lead and arsenic in sprays, as used, for example, in nurseries to control the Japanese beetle, may leave residues in the soil that are toxic to growing plants.

The whole problem of the interrelationships of these elements in soils, plants, and animals needs more intensive research. What, for example, are the functions of the various secondary elements in life processes? It has been reported, without confirmation as yet, that boron is concentrated in the pistils of flowering plants, barium in the eyeballs of animals, zinc in the reproductive glands, bromine in the pituitary, and cobalt and nickel in the pancreas. One difficulty in the research work is that only the most refined methods of analysis can be used where such minute quantities produce such powerful effects.

The secondary element selenium deserves special treatment as the cause of the fatal alkali disease among animals, characterized by loss of hair and hoofs, lameness, liver lesions, and edema (dropsy). The disease was first noted in 1857, but the cause was unknown for 75 years. In 1928 it was traced to the consumption of grain and other vegetation grown on definite soil areas, and a few years later the cause was found to be selenium in the grain. Survey work showed that soils from certain geological formations are selenium-bearing, but that poisonous concentrations remain only under conditions of low rainfall; under irrigation or in humid areas the selenium is washed out of the soil. Toxic areas have been located in South Dakota, Nebraska, Wyoming, Kansas, Colorado, New Mexico, and Montana. Soils containing 1 part of selenium per million, or even less, may produce vegetation that is poisonous.

Plants differ in their absorption of selenium and their tolerance to it. Range animals tend to avoid the poisonous plants except when other vegetation is reduced by overgrazing. Animals passing through a selenium area have been known to die in large numbers overnight from eating toxic vegetation.

Soil and plant relationships are most evident in the case of native vegetation, since this develops in balance with the climate and the soil. The soil itself, in fact, is formed under the influence of the vegetation that grows upon it, and in the long run this may contribute more to its character than the geological materials from which it was originally formed. The native vegetation was used by primitive man and by early settlers as a guide to the choice of croplands or grazing land, and it is still used in reconnaissance surveys to indicate boundaries between soil types. In general, broad plant communities throughout the United States will be found to coincide with soil associations; though there are some interesting exceptions, where, for example, a certain factor such as rainfall has a more powerful effect on soil development than on plant growth, or vice versa. Various plant communities broadly indicate regions of cool or warm climate; high or low rainfall; frequent drought; permanently dry, moist, or flooded subsoil; and land valuable for agricultural production or for grazing. On western raw lands, certain plants indicate the best, the medium, and poorest soils for small grains and for the production of forage; and in the case of grazing land, they are correlated with the carrying capacity of the range.

Fundamentals of Soil Science

Soil science in modern times has developed along two general lines. In western Europe it followed the theory of the great German chemist Liebig that productiveness depends on maintaining the correct balance of mineral elements in the soil. Experiments and practices resulting from this theory greatly increased crop production, but it is known today that the balance of mineral elements does not tell the whole story.

Russian students of the soil took a different approach. The scientists in that vast land saw a great variety of soils with marked regional differences. In trying to discover the why of these differences they soon saw that the soil is very much like a living thing,

born of parent rock and slowly developing under the influence of climate, vegetation, and relief, or the topography of the land. Differences in these forces make differences in soils, and the soils can be classified in great groups each of which has its own peculiar characteristics.

Soil scientists in the United States have been influenced by both viewpoints. They have carried on plot experiments based on the chemical-balance theory, but also, especially under the influence of the late C. F. Marbut, they surveyed and classified soils somewhat according to the Russian concepts. Because of similarities between soils in the United States and those in Europe and Asia, much from both schools is helpful to us, but there are unique problems in this country that also necessitate a different approach from that in either Europe or the Soviet Union.

Physics, Chemistry, and Biology of the Soil

The broad differences in soils may be easily seen when the soil layers are exposed, as by digging a trench in a field. These layers are called horizons, and the whole arrangement of the horizons from top to bottom is called the soil profile. In the surface layer, called the A horizon, life is most abundant, and this is the horizon that is normally cultivated for crops. Below it is the B horizon, which may be heavier and have an accumulation of clay. The A and B horizons together are the true soil or solum. Below them is the C horizon, the weathered parent material from which true soil can be formed only by the slow, complex processes of soil formation. Soils formed under different conditions have different profiles, like different races of people, and some do not have all three horizons.

The soil as a whole is a mixture of solids, liquids, and gases or air. The solid portion is partly inorganic, derived from rock, and partly organic, derived from living things such as roots and bacteria. These solid particles range in size from gravel and stones, through sand and silt, to clay. The texture or "feel" of the soil is determined by the proportion of particles of different sizes.

But the particles also cling together in groups, as anyone can see by picking up a handful of soil. The sizes and shapes of these groups, and their resistance to breaking down, make what is called the structure of the soil. It is now known that structure plays a large part in the productivity of different soils, affecting the ease with which roots can penetrate, the rate of absorption and movement of water, and the resistance of the soil to erosion. It is just as important to maintain good structure as to maintain a good chemical balance. Granular and crumb structures are the best for crop plants, and these structures normally develop where grasses and legumes have been grown, but also sometimes under forests.

In addition to texture and structure, soils have color. Different colors result from the presence of much or little organic matter and from the accumulation of certain chemical compounds. Black or brown soils are usually considered the most fertile, red or reddish-brown next, and yellow, gray, and white the least fertile.

Clay, which has the smallest particles of any solid material in the soil, deserves special mention. These very fine particles, most of

which cannot be seen even under a microscope, are called colloids. They represent the last stage in the break-down of larger pieces. Some are made from organic matter, some from mineral matter. The clay particles or colloids are the pantry in which plant foods are kept, the storage place where chemicals are held, to be gradually released to nourish plants. The kind and amount of the clay or colloid portion of a soil is therefore extremely important in determining its fertility.

But before the nutrients can be actually absorbed by roots, they must be transferred to the liquid portion of the soil, the soil solution. This might be roughly likened to a thin chemical soup, made of minerals dissolved in water, which occupies the pore spaces between the solid particles of soil. That is, the soil solution shares these pore spaces with air. Air in the soil supplies plant roots with oxygen, and it is important to maintain the supply by proper drainage.

We live in a moist world, and of all chemical compounds water is the most wonderful and universally useful. A severe drought emphasizes the value of a soil with good moisture-holding capacity. Water is constantly moving in the soil, pulled downward by gravity, and creeping upward, downward, and sidewise in the tiny cavities or pores through the operation of capillary forces— the same forces that pull ink up in a blotter. How water is retained in the soil and how it moves is an interesting but complex subject for study, closely tied up with laws of physics. The vital point is what is called the available water—the amount that is left after all excess has been drained away by gravity, but before so much has been removed by evaporation and transpiration that plants wilt. This available water is capillary water; it is held by capillary attraction in the minute pore spaces. Since structure determines the size and shape of the pore spaces, it is most important in determining the capacity of a soil for holding a large amount of available water.

Soil chemistry today is also an extremely complex subject, but this may be partly because not enough is known to make simple relationships always clear. As knowledge increases in any science, relationships that look complex can often be reduced to fairly simple laws.

Soil chemists at present are giving major attention to the colloids or clay particles. Taken all together, the particles in a pound of dry clay have an enormous surface area—probably enough to cover 5 acres of ground if they could be opened up and spread out. This great surface area makes a fine field for chemical reactions.

Through ages of washing, the soil colloids in humid regions have lost much of their lime (calcium), potassium, and some other elements, but they retain minerals that slowly become available to plants by being transferred to the soil solution. In dry-land regions the colloids have kept much more of the calcium, potassium, and sodium that was in the original parent material. In prairie regions they have been enriched by additions from the organic matter of the grass cover. In northern forested regions, still different changes occur. In general, colloids with a relatively high silica content are better able to hold plant nutrients than those low in silica. Such broad differences can be analyzed by the chemist, and this knowledge is used in various ways, but the smaller differences, which may also be important, still elude analysis.

One of the activities of special importance in connection with colloids is the phenomenon known as base exchange, and this too is receiving a good deal of study. When a fertilizer salt—potassium chloride, for example—is added to the soil, not all of it goes into the soil solution. Some of it changes place in the colloid particles with calcium, sodium, and other mineral base elements, which are then released to the soil solution. The part of the potassium that goes to the colloid is held there in a form that is not readily soluble, and thus it is conserved for future use. Where hydrogen and calcium are involved, base exchange is a large factor in the acidity of the soil. In fact a better understanding of the complicated reactions of base exchange is vital in many ways to the working out of better soil-management practices.

The question of acidity is somewhat better understood since accurate methods of measuring the reaction of the soil have been worked out. One of the most useful of these is the simple pH scale. It consists of whole numbers and fractions that indicate the concentration of hydrogen (H) ions in proportion to hydroxyl (OH) ions in a solution. An excess of the former makes an acid soil; of the latter, an alkaline soil. Soil reaction is now commonly expressed in terms of pH values.

Studies of colloids, base exchange, and soil reaction are merely three examples of present-day research in soil chemistry. The field is wide, and while theoretical knowledge is being built up, practical applications are constantly being made that are of value in crop production.

The scientific study of the soil takes in not only physics and chemistry but biology. All living things supported by the soil return to it in the end, to be broken down by untold numbers of micro-organisms and become the complex substance called humus. This humus is in effect a storehouse of plant nutrients that are gradually released as it is still further decomposed into simple mineral salts, carbon dioxide, and water. But humus represents more than stored plant nutrients; intimately mixed with soil, it has a great deal to do with creating and maintaining good soil structure.

There is no true soil without organic matter. The quantity of humus, however, depends primarily on climate and vegetation. Climate determines the rate and time of decomposition; vegetation determines the amount and kind of organic substance added to the soil each year. In grassland, for example, the quantity of humus in the soil is large; additions each year are not great, but they have been gradually built up because climatic conditions have made the rate of decomposition slow. Eventually all soils under natural conditions reach a state of balance, when the additions of humus from native vegetation equal the removal by decomposition. Between the great regional soil groups there are striking and characteristic differences both in the amount of humus and its distribution through the soil profile.

When man clears away or plows up the native vegetation, he disturbs or destroys this balance. He may or may not damage the soil, but he must provide for an adequate supply of humus in one way or another if productivity is to be maintained.

The living microscopic organisms that swarm in the soil are the agencies that break down raw organic material into humus, and this

again into simpler elements. They do this in the process of getting food for themselves and building up their own bodies. They in turn die, by uncounted billions, to add to the soil organic matter.

The easily decomposed sugars, starches, and proteins in plant and animal remains are broken down first by these micro-organisms; then the celluloses that make cell walls, and the fatlike lipoids; and last the tough lignins or woody substances, which may remain for a long time in the humus state. When bacteria attack the proteins, one of the products is ammonia, which is absorbed by the soil. From the ammonia, nitrites are produced by further bacterial action. Another onslaught of bacteria changes the nitrites to nitrates, which can readily be utilized by plants. Other bacteria live in the roots of legumes, from which they get food; and in return, they fix nitrogen from the air and build up the supply in the soil.

Bacteria are not the only micro-organisms that carry on the processes of decomposition. Fungi are numerous and active, especially under forest conditions. Some of them, the mycorrhiza, live in close association with the roots of plants, somewhat like the nitrogen-fixing bacteria, in an arrangement that is advantageous to both the plant and the fungus. Then there are protozoa, one-celled animals that feed on the bacteria, and slime molds (myxomycetes) which apparently feed on bacteria and fungi. Going up the scale of size, there are nematodes, worms, insects, and larger animals living in the soil and each having some effect upon it.

Formation and Classification of Soils

Physically, chemically, and biologically, then, the picture of the soil is one of ceaseless change. The soil remains what it is only because something is always becoming something else. In this change, additions are normally compensated by subtractions, and the endless interplay of forces remains in balance. Broadly, the process of soil formation as it is now understood is like this:

The beginning is parent rock—geologically a broader term than it is in common usage, because sand and dust and other soft materials are called rock by the geologist. Rocks are classified into three main groups: (1) Those made from molten material (igneous rocks), often volcanic in origin; (2) those made of material deposited by three agencies—water (sedimentary rocks), wind (eolian rocks or loess, which is really dust), and glaciers (glacial rocks); (3) those made from one of the other kinds by intense heat or pressure (metamorphic rocks). These groups contain many different kinds of rocks of varying composition, some rich and some poor in minerals that can be used by plants. Naturally the parent rock has an effect on the soil made from it, but usually this effect is profoundly modified by other forces.

Physical weathering breaks rock into fragments. It is split by slow, irresistible forces—the uneven expansion and contraction caused by heat and cold, and the wedging of ice and of roots. Large fragments become small particles through grinding by rivers, glaciers, landslides, and avalanches, and scouring by winds. Meanwhile the rock is also chemically weathered, and some of its compounds—particularly of potassium, calcium, and magnesium—are dissolved. Decaying vegetation mixes humus with the rock particles, and plant

roots pull up minerals in the water they get from deeper soil layers and add these to the surface layer. Micro-organisms are active either continuously or in great seasonal waves. In all of these soil-forming processes climate, including temperature and rainfall, plays a vital part. Relief, or the slope of the land, is also extremely important, controlling drainage, run-off, percolation, and erosion. Finally, time itself is a factor in soil formation. Certain soils in humid regions may be formed in 100 years or less. Others, particularly in dry regions, require ages.

The interaction of all these forces in varying degrees has produced soils with marked individual characteristics, which are used as the basis for the modern system of soil classification. The broadest grouping is into three orders:

(1) Soils produced under normal conditions from well-drained parent material acted on by climate and biological forces. These are called zonal soils.

(2) Soils in which either the parent material or the slope of the land (relief) has produced an effect that overbalances all other factors. These are called intrazonal soils.

(3) Soils in which the parent material has remained just about as it was originally, almost unchanged by any forces. These are called azonal soils.

Within these three orders, certain processes or conditions produce many great groups of soils:

(1) In the zonal order: (a) Soils that normally have an accumulation of lime. In the arid regions, these include the great groups known as the Desert, Red Desert, Sierozem (gray), and Brown soils. In the grassland regions they include the great groups known as the Reddish Brown, Chestnut, Reddish Chestnut, and Chernozem (black) soils. In the forest-grassland transitional regions they include the great groups known as the Degraded Chernozem and Noncalcic Brown soils. (b) Soils in which there is an accumulation of peaty organic matter on the surface, and in which clays and iron compounds have moved down to lower layers. This process is known as podzolization, and it takes place under forest conditions. The soils produced are the great groups known as the Podzol and Brown Podzolic soils. (c) Soils in which there is a progressive decomposition of rock minerals by hydrolysis, and in which these minerals are converted into silicic acid, aluminum hydroxide, and iron hydroxide, or related products. This process is known as laterization and it occurs in warm-temperate and tropical forest regions. The soils produced are the great groups known as the Yellow Podzolic, Red Podzolic, Yellowish-Brown Lateritic, Reddish-Brown Lateritic, and Laterite soils.

(2) In the intrazonal order: (a) Soils characterized by an accumulation of salts, or produced from soils in which there was formerly an accumulation of salts—the Solonchak, Solonetz, and Soloth great groups. (b) Soils formed under water or in moist areas, often characterized by bluish or greenish waterlogged layers—the Wiesenböden, Alpine Meadow, Bog, Half Bog, Planosol, Ground-Water Podzol, and Ground-Water Laterite great groups. (c) Soils exceptionally high in calcium—the Brown Forest and Rendzina great groups.

(3) In the azonal order: (a) The Lithosols or stony soils, (b) the alluvial soils, made of fresh alluvium laid down by rivers, and (c) the dry sands.

Not only does each of the great groups of soils have definite visible characteristics that can be used for identification; each also has a characteristic degree of productivity for certain plants, it is suited to definite uses, and it calls for a certain kind of management. Red Desert soils, for example, are suitable for grazing in large units or for irrigation; Chernozems, for small grains and corn; Podzols, for hay and pasture; and good alluvial soils, which include some of the richest in the world, for practically all crops.

The great groups are further subdivided into soil series, the series into soil types, and the types into soil phases. These subdivisions

express various influences that make local soils within a great group somewhat different from each other. Such differences are shown on soil maps. For some years the Soil Survey Division of the Department of Agriculture has been engaged in mapping the soils of the United States. The maps are accompanied by accurate descriptions of the soils, from notes made in the field and thousands of laboratory analyses; and recently tables showing productivity ratings have been added wherever significant figures could be worked out. Soil maps with their accompanying descriptions are essential to every agency interested in land use, and when they show sufficient detail they give the individual farmer sound information to supplement his own experience in planning farm-management practices.

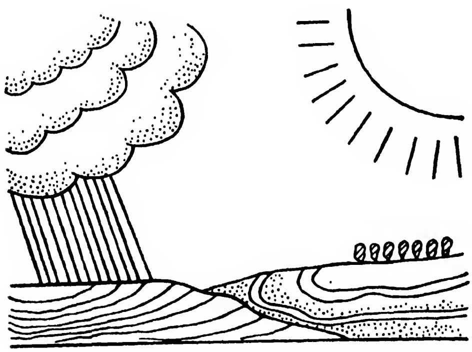
The scientist who spends his life studying this dynamic thing, the soil, comes to have a profound respect for it. If he has any philosophic turn of mind at all, he can hardly help seeing the soil as the fundamental thing in all human activity. He sees that certain kinds of soil give rise to certain kinds of civilization. Men who live on the Chestnut soils of the temperate to cool semiarid regions, growing grains and grazing cattle in great units, looking out on broad expanses of grassland, will have different economic problems and will develop a different civilization and have different attitudes of mind from those who live on meager Podzol soils, once covered with forests, where farms generally are small; and different also from those who live on the rich, deep alluvial soils of the great river valleys. The ingredients of the soil, a lack of this element or a superabundance of that, may even affect the bodies of men, or influence their glands and therefore their psychology, through the food grown on the soil.

In other words, many human activities not ordinarily associated with the soil may be traced back to its influence. When men migrate from one kind of soil to another with which they are unfamiliar, for example, they may abuse the new soil and it may take them a long time to become adjusted to its needs. Stable civilizations are associated with long familiarity with a given soil; they grow out of it and are rooted in it. If disturbances arise that upset the relationship of men with the soil, such as conquest by an alien nation, or long-continued economic depression, they may lead to neglect or abuse of the land, and this may be followed, under the right conditions, by its ultimate ruin and forced abandonment.

A stable, healthy, and vigorous civilization demands a proper adjustment of men to the soil, and opportunities for them to make this adjustment. That is why the soil problem is so important in the United States.

Part I Soils & Men

The Nation and the Soil



THERE ARE both private and public purposes in the use of the soil. It is widely acknowledged today that public purposes are not being achieved satisfactorily. Partly this is because of inadequate knowledge of physical techniques and partly because of faulty social organization for promoting legitimate private interests. The formulation of a desirable public soil policy requires an understanding of the broad human problems with which the social scientists deal and the relationship of the technical findings of the soil scientists to these problems. Wise statesmanship demands that the knowledge of both groups be utilized.

The objective in this section of the Yearbook, therefore, is fourfold: *(1)* To describe as clearly as possible what the public purposes in soil use are or should be. This is done in the first article. *(2)* To indicate the present extent and nature of soil misuse. This is done in four articles, each of which deals with certain aspects of the problem. *(3)* To discuss possible social and economic causes of misuse of the soil. This is done in four articles dealing with land policy, farm tenancy, agricultural finance, price relations, and economic instability. *(4)* To suggest remedial action. This is done in six articles that deal with education and research, public land policy, policies for private lands, direct aids to farmers, and broad questions of economic stability. The final article in the section is concerned with the soil and the law.

THE central public purpose in the use of land or soil for agriculture may be broadly stated as that of sustaining on a relatively permanent basis the highest possible standard of living for the people of the United States. Most people will agree with some such statement of what public purpose ought to be, as long as its terms are sufficiently broad and general to permit each one to write in his own specific meaning. It is when efforts are made to interpret such statements in terms of present policies that divergence of viewpoint arises. For this reason, it is important to indicate some of the more significant issues to be met in clarifying national policy. This article deals with the related problems of population distribution and soil conservation.

Public Purposes in Soil Use

By Carl C. Taylor, Bushrod W. Allin, *and* O. E. Baker [1]

THE DISTRIBUTION OF PEOPLE

IF IT IS to be assumed that our soil resources should be used so as to maintain permanently the highest possible standard of living for the people of the United States, then the density and location of the population are of central significance. The outlook now is that the United States will have a stationary or declining population by 1960, unless greater immigration from abroad is permitted. Agricultural efficiency has increased enormously in the past, and there are good grounds for assuming that it will continue to do so in the future. The proportion of the population on farms has declined since 1870 from more than 50 percent to about 25 percent, and there is still more manpower on farms than is needed to meet all prospective domestic and foreign demand for food and fiber under peacetime conditions.

From these facts, the conclusion is reached that all the natural increase—as represented by excess of births over deaths—and probably some portion of the present farm population will have to find other than farm employment if the historic trend of a rising material plane of living is to continue. Shall a national economic policy for soil use promote or interfere with the tendency for agriculture to support a smaller and smaller proportion of the population? Any policy that looks beyond the emergencies of the present will in all probability do one or the other. A policy aimed at a smaller farm population would be based, of course, on the assumption that non-

lation
Office of Land Use Coordination; and O. E. Baker, [illegible] Population and Rural Life, Bureau of Agricultural Economics. The section headed Conservation Policy is by Bushrod W. Allin.

agricultural enterprises would expand sufficiently to absorb the rest of the people in gainful employment.

As long as there were unoccupied agricultural areas in the western United States, population flowed constantly toward them. This migration, beginning in colonial days, moved with increasing speed for the 100 years from 1790 to 1890, but slackened after that period, in part because the supply of good land had been exhausted, and settlement was advancing onto poorer lands. Long before the westward migration had ceased, a movement toward the cities and towns became

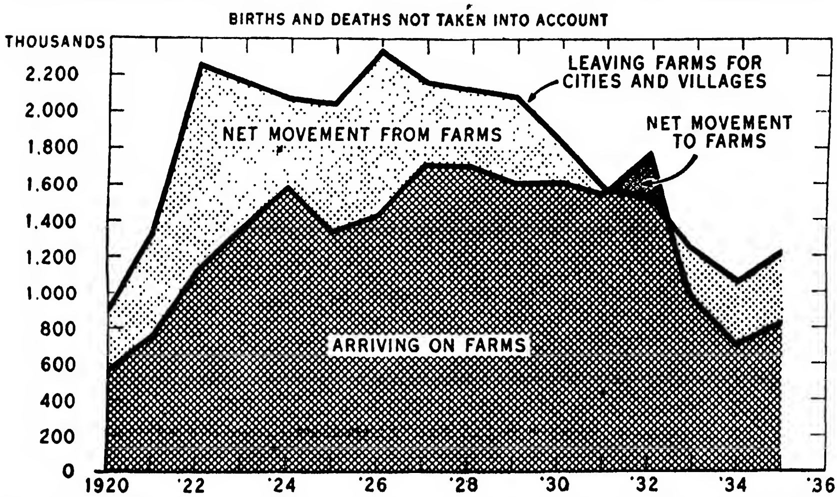


FIGURE 1.—Movement to and from farms, 1920–35, births and deaths not taken into account. From 1922 to 1929, inclusive, migration from the farms to the cities exceeded 2,000,000 each year—probably a larger movement than ever before in the Nation's history. Those were prosperous years in the cities and relatively hard times for agriculture. But during those years many people returned to farms. Thus the net migration from farms averaged less than 700,000 annually. As the depression developed and jobs became scarce, the movement from farms dropped notably, while that to farms remained almost stationary through 1932, exceeding the movement from farms in that year, and thereafter fell to less than one-half of the peak level.

the dominant type of migration. It reached its highest tide in the decade following the World War, and then, as in the case of the westward movement three decades earlier, began to slacken. By 1932 the urbanward trend had reversed itself, and the net flow of population was from cities and towns to farms. This reversal, however, was apparently a depression phenomenon, for since 1933 the net flow again has been urbanward (fig. 1).

If migration from farms to urban communities should cease, and if the 1930 rate of natural increase in the farm population should continue, certain farming areas would soon be so overpopulated as to bring about a very different type of agriculture and farm life than has ever been known or contemplated in this Nation. The present rate of population growth among farm families would nearly double the farm population in one generation among the Negroes in the South Atlantic States and among the whites in the East South Central

States, and would increase it 70 to 80 percent among both Negroes and whites in the West South Central States, among the Negroes in the East South Central States, and among the whites in the Mountain States. For the United States as a whole, the increase in the farm population would be 70 percent among whites and 80 percent among Negroes. Such increases would mean that we would have a quarter century hence approximately 43,000,000 whites and 8,500,000 Negroes

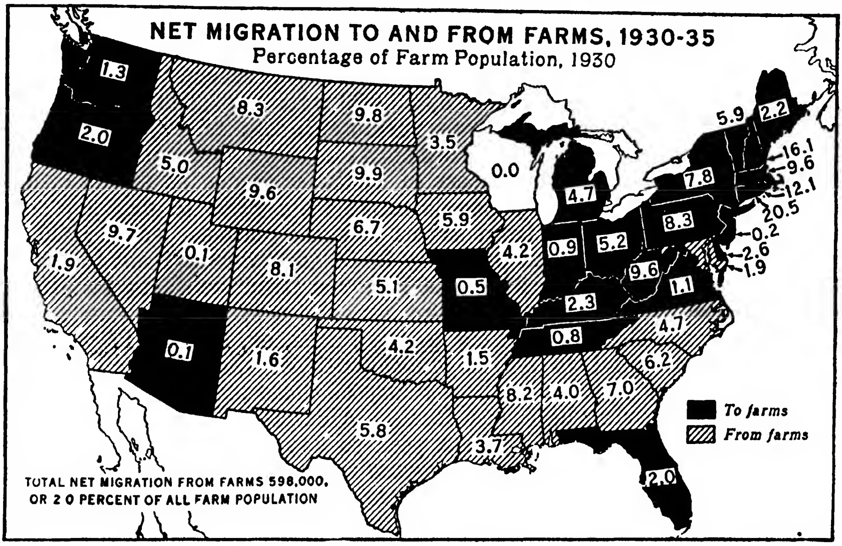


FIGURE 2. Between 1930 and 1935, in which was included the depression period, it can be seen that net migration from farms was chiefly from the Cotton, Wheat, and Corn Belts, whereas the migration to farms was for the most part either to areas adjacent to industrial communities or to the poorer land areas of the Nation.

living on farms that is, a farm population fully two-thirds larger than in 1930.

No such development need be anticipated, for at least some net migration from farms to towns and cities will undoubtedly continue in the future; also the birth rate doubtless will continue to decline. The trend from 1910 through 1929, mostly years of urban prosperity, was toward both an absolutely and a relatively smaller farm population. Although the farm population increased from 1929 to 1936, it again resumed its downward direction in 1937. There were about 1,900,000 fewer persons on farms in 1930 than in 1910, and 1,100,000 fewer in 1926 than in 1922—notwithstanding a natural increase in the farm population of approximately 10,000,000 between 1910 and 1930, and of approximately 2,000,000 from 1922 to 1926. Even during the depression period from 1930 to 1935 there was a net migration from farms of about 600,000 (fig. 2).

In interpreting these data on recent trends, three characteristics of migration need to be noted: (1) The net urbanward trend itself, (2) the process by which the net movement has taken place, and (3) the fluctuation in the total number of moves to and from cities.

The magnitude of migration from the farms can be estimated with confidence only for the decade 1920–30, but it is possible to estimate roughly the net migration from rural nonfarm (mostly village) areas since 1890. The net migration from rural to urban territory during the decade 1890–1900 was apparently about 2,500,000; during the next 10 years it was about 3,500,000; and from 1910 to 1920, a period which included the World War years, it was probably 5,000,000. In the decade 1920–30, it was more than 6,000,000. More than a million persons apparently moved from farms into rural nonfarm territory during the decade, while a similar number moved from the rural nonfarm into urban territory. Of the 14,650,000 increase in the city population during the decade, about 5,000,000 were migrants from farms, over 1,000,000 were migrants from rural nonfarm territory, and probably 3,000,000 were immigrants from abroad. The remaining 5,000,000 to 6,000,000 represent the excess of births over deaths in the cities.

Each year a great many people move from rural to urban places and a great many move from urban to rural places. From 1920 to 1936, inclusive, there were probably 29,000,000 moves from farms to nonfarm areas and over 21,000,000 moves from nonfarm territory, mostly cities, to farms; that is, there were about 7,750,000 more moves from the farms than there were to the farms, or, for the 17 years, a net migration equal to about one-seventh of the total migration. There is no way of knowing how many of these moves represent the same persons moving back and forth. All that is known is that out of the total moves, varying from year to year, the residue of moves in one direction or the other represents the net shift of population as between rural and urban places. From year to year, the ratio of this shift to the total number of moves has varied greatly, from 1 in 3 for 1922 to only 1 in 155 for 1931 (*427*).[2]

Apparently, in times of general prosperity people have more money to spend in experimental relocation, and the psychology of prosperity makes them more willing to assume the risks of migration. Alternative opportunities are more diverse and better advertised, with the result that the flow of population both to and from farms is relatively great. But the net migration is always small in relation to the total movement. When there is general depression, however, migration in both directions is less and the net shift in population is a still smaller percentage of the total number of moves (fig. 3).

The people of no modern nation have been more constantly mobile than those of the United States in seeking better economic and social opportunities. If urban prosperity persists, it may be assumed that migration will continue to be the chief method of adjusting population to natural resources. But despite our record of enormous unguided migrations, the farming population of certain areas of the Nation is still greatly in excess of that which the soils of the areas should support. Misuse of the soils is one of the results; and the income from farming in these areas must necessarily be divided among too great a number of persons to furnish adequate standards of living. There are a number of such areas in the United States, areas of low agricultural productivity, serious soil erosion, excessive farm population, and high birth rates. Figure 4 shows a family in such an area. These are

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

TOTAL AND NET MIGRATION TO AND FROM FARMS, 1920-36

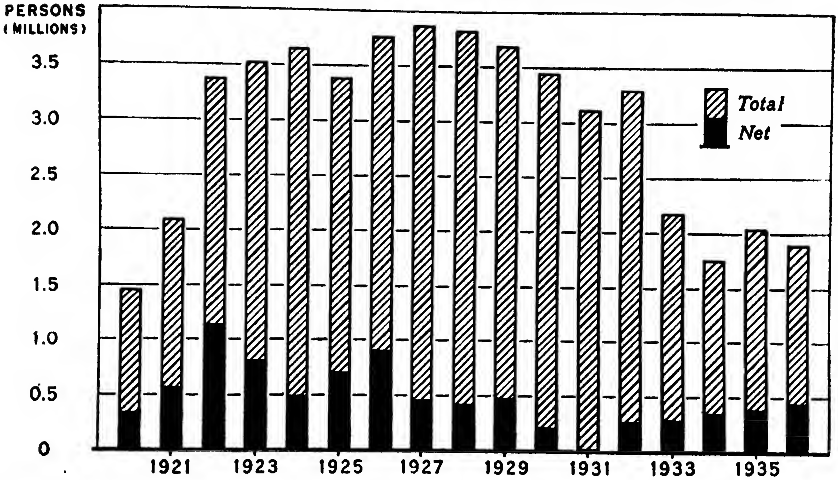


FIGURE 3.—Between January 1, 1920, and January 1, 1937, more than 50,000,000 moves were made from farms to towns, villages, and cities or from towns, villages, and cities to farms. During the whole period, the net migration was equal to at least one-seventh of the gross migration. The number of moves within a given year varied from as low as 1,456,000 in 1920 to as high as 3,867,000 in 1927, and back to 1,751,000 in 1934.

FIGURE 4.—The birth rate is usually high in areas of low agricultural productivity, serious soil erosion, and excessive farm population. (Farm Security Administration photograph by Lee.)

areas from which population should flow, either to other agricultural areas with richer soil resources or into nonagricultural occupations.

To a farm family of 10, living on a small, eroding farm and producing only one or two bales of cotton per year, parity prices still mean abject poverty. Should the Government encourage and guide the movement of such people, with a view to providing them with better economic opportunities and devoting the land to the use for which it is best suited? Obviously, there is no place for such people to go during a general depression. But should there be a positive governmental program for encouraging their migration when alternative opportunities exist? If so, in what direction should the Government attempt to move them, as a matter of long-time policy? Toward nonfarm occupations, or to better farm lands?

Those who argue that the movement should be toward nonfarm occupations point out that the relatively inelastic demand for farm products together with prospective improvements in agricultural efficiency make it impossible for any large proportion of the farmers in problem areas to find greatly improved opportunities in agriculture without encroaching unduly upon the opportunities of others engaged in farming. They contend that the food supply is pressing against the population, that there are real shortages of nonagricultural goods and services, and that demand for them is relatively elastic. By moving people from the poorest lands either to the outer edges of urban areas, where they may still practice part-time farming in connection with nonfarm employment, or into urban centers, the effect on the total volume of commercial agricultural production would be negligible.

Most proponents of this policy have no illusions as to the ability of the industrial system to provide employment now for the surplus farm population. But they assume that if the present system does not provide decent material standards of living for great numbers of underprivileged, it can be changed in such a manner that it will do so. They insist that if technological unemployment cannot be corrected by traditional expansion of the spheres of economic activity, then increased wages with more leisure and adequate programs for social security will lessen the general insecurity in urban occupations, and divide nonagricultural income more equitably among the nonagricultural population. There is nothing in this definition of desirable national policy that precludes the possibility of moving people from poor land to good land so long as the net effect is not to expand unduly the production of the national agricultural plant. Indeed, there is evidence that much unguided migration from poor land has been to good land from which former operators had moved to urban communities.

In opposition to the view that public policy should seek to reduce the proportion of the national man power engaged in agriculture, some people take the position that there is an essential conflict between a policy aimed at an ever-increasing material plane of living and a policy that is needed to provide the Nation adequately with many intangible values associated with rural life. It is pointed out, and correctly so, that there are other values besides economic values; and that many human desires find their fulfillment not in the material level of living of a highly industrialized economic society but in crea-

tive activities such as home arts, handicrafts, living and working out of doors with growing things, and in the development of rural community and family life. These things, it is contended, do not wholly fit into the modern wage, hour, price, market, and exchange economy. Those who hold these views are also generally pessimistic concerning the possibilities of making nonagricultural occupations secure, and insist that the security of a less commercial farming is preferable to the insecurity of employment for large segments of our urban population. They believe that rural poverty can be reduced sufficiently to make possible the attainment of the intangible values they seek, and that this can be done without decreasing the proportion of the national man power engaged in agriculture. Some are seriously disturbed concerning the prospective decline of the total population of the Nation, and point out that a continuation of the trend toward a smaller farm population will hasten the decline, because rural birth rates are higher than urban birth rates.

Fortunately, the choice is not necessarily between Fifth Avenue and Tobacco Road. There are middle-course alternatives. All will agree that rural slums, as well as urban slums, should be eradicated; and that in accomplishing this it is not necessary to expose the people to all of the vices and none of the virtues of urban life. If it is sound public policy to establish a "floor" below which industrial wages shall not fall and a "ceiling" above which hours of labor shall not rise, it is equally appropriate for the Government to fix minimum standards of agricultural soil quality and to designate as not to be used for agriculture all areas of land that fail to meet these standards. Past experience should be the principal evidence for determining such unsuitability of land. As rapidly as individuals now cultivating such land choose to move voluntarily to better opportunities, others could be denied the doubtful privilege of moving in and using it to eke out a bare existence.

It has been estimated that some 4 million people would have to move from portions of the southern Appalachians, the old Cotton Belt, the Great Plains, and other problem areas if a reasonable standard of living were to be maintained for the remainder of the population and the land devoted to its best permanent use (*8, p. 493*). The interpretation of this estimate, of course, depends mainly upon what is regarded as a reasonable standard of living. As used here, the phrase includes some very low levels of living, but levels that are definitely higher than those generally regarded as rural-slum conditions. Regardless of the precise number that may be agreed upon as the surplus population of problem areas, it is certain to be large; and much of the desirable migration, therefore, will be possible only if nonfarming opportunities expand sufficiently to provide necessary employment. Hence, one of the key problems is to be found in industry rather than in agriculture.

The record of past migration shows clearly that when nonfarm employment is more attractive than farming, large numbers of people will migrate from farms to cities and villages and to rural nonfarm territory. The net number moving from farms during the relatively prosperous decade of the 1920's was more than 6 million. All States except California, Massachusetts, and Rhode Island reported a net migration from farms during this period (fig. 5). Those having the

heaviest migration in proportion to the total farm population included Maryland, Virginia, West Virginia, Kentucky, Tennessee, Georgia, and South Carolina. With the exception of Maryland, these States are noted for their rural problem areas—areas of excessively heavy population pressure on available resources, low per-capita farm incomes, and high rural birth rates. In general, it is this same type of area (excepting some portions of the Cotton Belt) in which the farm population increased most during the depression years from 1929 to 1933 (*127, pp. 71–85*), because industrial unemployment either prevented normal emigration or induced immigration. A disproportionate number of such areas have also had the larger percentage of

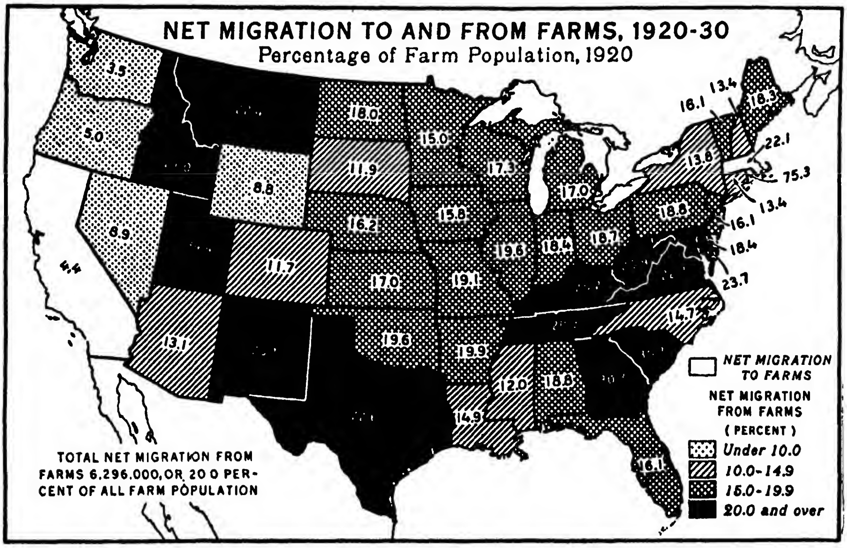


FIGURE 5.—Between 1920 and 1930, all States except Massachusetts, Rhode Island, and California had a net migration from farms, 12 States losing 20 percent or more of their 1920 farm population. All of these States were predominantly rural.

their populations on relief rolls, and many of them can be described properly as rural slums.

A policy for rural-slum clearance is one for promoting proper use of soils in problem areas, and this is necessarily a long-time policy. As such, it can and should operate in accordance with available opportunities. A definite public program to clear out the surplus population of the problem areas requires no decision now as to how many should be resettled by the Government. It requires only continuous and persistent efforts to retire permanently from agricultural use, by public purchase or other appropriate means, submarginal lands operated by people who are both willing and able to move to areas or occupations that provide better opportunities. But care should be exercised in promoting such migration, lest the migrants soon exhaust their resources and become dependent on relief. It is improbable that many middle-aged or old people in such areas will be both willing to move and able to obtain employment elsewhere.

If handled in this manner, governmental activity in connection with such a program would be greatest in periods of industrial prosperity when the population of problem areas is least and when alternative opportunities are greatest. The question of whether the surplus population should be encouraged to remain in agriculture and move to better land or seek nonagricultural employment must be answered in terms of available economic opportunities. Moreover much individual consideration is necessary. For those who, it appears, should remain in agriculture, the credit facilities of the Farm Credit Administration or the Farm Security Administration should be made available. In addition, many families will need agricultural and economic guidance. If the economic system can be made to yield a generally rising material plane of living, the people who should leave the problem areas will either move toward nonagricultural occupations or to better lands released by others who enter nonfarm employment. If, on the other hand, the general plane of living should not rise, both farm and nonfarm groups would have to share their income and perhaps some of their opportunities with the less fortunate.

It may be blind optimism to assume that the level of living can and will be raised, but it is the only assumption to make in planning for progress. As a practical matter, however, it is certain that whatever may be done by the Government to promote rural-slum clearance will fall far short of the ideal. Large numbers of subsistence farmers will continue to cultivate eroding hillsides in problem areas for many years to come, in spite of any public land policy or program that is likely to be adopted. Many will continue to choose subsistence agriculture as a life occupation in preference to other occupations which might support a higher material standard of living.

Even so, the attainable goals of positive public action in the field of land use are large. In seeking these goals, it should be recognized that a Government-sponsored program for retiring submarginal land from cultivation must proceed on the assumption that it is possible to provide more desirable forms of security against the hazards of unemployment than that afforded in the past by such lands, and that this will be done to an increasing extent. The assumption is valid, despite the fact that poor land areas have served during the depression as a haven of refuge for a disproportionate share of both the natural increase in the farm population and the back-to-the-land migrants from urban centers.

Collateral implications are also important. Land that is submarginal for full-time farming may be satisfactory for part-time farming. In the classification of such land, therefore, it is important to consider the possibilities for decentralization of industry. In general, the prospects seem to favor a spreading type of decentralization into the periphery of existing industrial centers rather than large-scale dispersion of industry to remote rural areas (*128*, *pp. 317–344*). This means that if subsistence farmers on the poorest lands in the problem areas are to be advanced to the status of part-time farmers, a large proportion of them will have to move; and the lands they now operate will have to be consolidated into larger, more economic units or devoted to forestry and other uses.

CONSERVATION POLICY

In the preceding analysis, the broad public purpose in soil use was interpreted in part to require that the Government discourage the use for agriculture of soils that are inherently too poor to support reasonable living standards, that it seek to eliminate overcrowding in certain rural communities, and that it follow economic policies designed to provide the surplus farm population with at least part-time employment in nonagricultural occupations. To make these suggestions at the outset is to proceed on the principle of "first things first." The first concern is people, not soil, and especially people at the bottom of the economic pyramid.

From the standpoint of soil conservation, these adjustments are intended to establish a relationship between population and soil resources that will permit soil maintenance without requiring individuals to make an undue sacrifice of present income. Such adjustments would tend definitely to promote soil conservation by making possible the restoration to grass and trees of much land unsuited for permanent cultivation.

About 415 million acres of land in the United States was classified by the census in 1935 as cropland. It has been estimated that 18 percent of this total, or 76 million acres, is unsuited for permanent cultivation under price levels similar to those that have prevailed since 1920. This is either because the slope of such land is so great that under cultivation it is impossible to control erosion by known practices that are economically feasible, or because the soil is inherently too poor to support reasonable living standards when used for cultivated crops.[3] The shifting of much of this land to its best permanent use, such as pasture, woodland, or wildlife habitats, would inevitably result in a redistribution of population. Yet even if this could be done, it is obvious that there would still remain the problem of conserving agricultural soil that should be kept in cultivation.

Of the remaining 339 million acres now classified by the census as cropland, 178 million acres, or 52 percent, is being permitted to erode seriously, while 161 million acres, or 48 percent, can be cultivated indefinitely under present practices without serious erosion injury. What is more, the erosion that is now occurring on the 176 million acres can be controlled by practices that have been demonstrated to be economically feasible for owner operators. Erosion on the public domain and on privately owned pasture lands can be reduced by controlled grazing.

To pass the soil on to succeeding generations as nearly unimpaired as possible is generally recognized as a worthy public purpose, but to formulate a sound policy for doing so is to weigh expected benefits and costs. Benefits cannot be measured in dollars. Approximately 1 billion acres of the land area of the United States is in farms. Assuming that the average value per acre of this land were $50, the total value would be $50,000,000,000 or hardly one-third more than the national debt. Obviously, the public value of the farm land of the United States is not simply $50,000,000,000. The total dollar

[3] These estimates were made in the summer of 1937 by the Soil Conservation Service and the Bureau of Chemistry and Soils, with the assistance of the land-grant colleges. Estimates by the colleges were based in part upon results of work done previously by county agricultural planning committees. For further details, see p. 95.

value of the land would probably be greater if half of it were destroyed by erosion, but the Nation generally would be only half as "rich" in soil resources. Moreover, the wisdom of a policy to reduce erosion on any particular parcel or portion of the Nation's farm land cannot be determined solely by comparing its present and potential dollar value with the probable cost of erosion-control measures.

Expected benefits from public action to save the soil are estimates of future needs for soil. Is all the soil needed, and for what purpose? The 76 million acres that should be retired permanently from cultivation and devoted to less intensive though profitable uses is not needed now for producing cultivated crops, because there are 108 million acres not now in cultivation that are of better quality and have gentler slopes. These better lands consist largely of plowable pastures, brush or timber lands, and some areas that can be economically drained or irrigated. Thus it is possible actually to increase the size of the national agricultural plant and at the same time retire 76 million acres from cultivation.

Then why be concerned about saving the soil on such portions of the submarginal land as are now threatened by erosion? It should be saved despite the fact that the Nation is approaching a stationary or declining population, and even though there is no prospect of an immediate shortage of food, feed, and fiber. The outlook for the more distant future is by no means clear.

> It is a first principle of political science that the State has immortal life. States have perished in the past, but political and economic science cannot take into account the possibility that our own national life will ever cease to exist. All wise plans must be based upon the hypothesis of continued national existence (*104, pp. 36–37*).

Obligations of the present generation to those of the future cannot be precisely defined, but every step forward in civilization means increased regard for the interests of the future.

Though it were certain that in the remote future a substantial portion of present cropland would not be needed to produce agricultural products for domestic purposes, there is no positive assurance that it would not be valuable in production for an export market. Prospective population increases and continued industrialization in the Orient suggest at least the possibility of future demand for American farm products. Offsetting considerations, of course, are to be found in the chances that science and technology will continue in the future to work as great wonders as in the past. But quite aside from its possible usefulness for agricultural purposes, the soil will certainly serve the Nation better where it is than by muddying creeks and rivers, or choking stream channels and costly reservoirs. If kept on the land, it helps to conserve water and thereby reduces the destructiveness of floods, and in most places it will contribute to more sightly landscapes and more abundant wildlife.

If it is desirable to save the soil on the 76 million acres that have been classified as unsuitable for continued cultivation under present economic conditions, it is still more important to reduce erosion on the better lands. So far as agricultural use is concerned, however, the case for saving all or most of the topsoil rests on the same principles as an accident or health insurance policy. Part of the soil may never

be needed, but this is not certain. The premium required for protection against the uncertain hazards of the future should be paid, if it is not too large.

The necessary cost of conservation that is chargeable to benefits to be derived in the remote future is certainly a small proportion of the total cost, because requisite changes in economic policy are almost entirely justifiable for more immediate purposes. Such changes may involve public purchase of submarginal land and resettlement of the people, changes in land tenure looking toward reduction and improvement of tenancy, greater exercise of the police power of the State by rural zoning and other means to prevent antisocial uses of land, creation of cooperative soil-conservation and grazing districts, and other activities related to taxation, credit, and industrial policy. All of these may be regarded as multiple-purpose activities, the benefits of which are of vast importance to people now living. So greatly in excess of any necessary public costs are the benefits to be expected that a program of required adjustments might properly be undertaken even if it had little or no relation to the distant future. The same reasoning applies to programs involving cash payments from the public treasury for conservation. These would not be made and could not be justified as long-time measures if their only purpose were to conserve soil. But the adoption of soil-conservation practices can and should be made a condition for receiving payments that are defensible for other reasons.

Thus the purpose of conserving the soil is not solely to protect the interests of the more remote future. Conservation for such a purpose has never had any popular appeal, and probably never will have. To be successful, an adequate soil-conservation program must serve the farmers' interests as well as the public interest. The divergence of these interests with respect to soil use is now too great, but it can be narrowed greatly by institutional changes that alter the relations of men to land. Thus conservation for the more distant future can be either an inevitable result or a possible accompaniment of justifiable public action needed for achieving immediate purposes. Interpreted in this manner, erosion control becomes one of many means to an end—the end being the best permanent use of the soil. It occupies no unique position in the complex of public policies needed for promoting the welfare of men. If the broader problems relating to land tenure, farm prices and income, education and community life are treated properly, the soil can and will be saved. Otherwise, half of the 447 million acres suitable for permanent cultivation under prospective prices and best conservation practices will eventually be lost, because 236 million acres are threatened by erosion under present institutions and practices.

Control of erosion, however, is not synonymous with maintenance of soil productivity. The latter includes also the replacement of plant nutrients lost through cropping as well as the maintenance of a desirable soil structure. Technically, all three factors are interdepependent, but from a long-time point of view the loss of the soil itself is most important because it is generally irreplaceable, whereas plant nutrients and soil structure can be restored. This difference, however, means only that the primary public interest in soil conservation

for the more remote future is in erosion control. So far as immediate interests are concerned, soil erosion and depletion of soil fertility both reflect economic and social conditions that are of grave national concern.

Appropriate national policy requires neither hair-splitting calculations as to whether this acre or that one should be saved, nor fine distinctions between the consequences of soil losses from erosion and of those from other causes. It does require recognition of the various public purposes in soil use. The more important of these are: (1) Secure farm homes, (2) adequate and stable incomes for farm people, and (3) continuous and abundant supplies of farm produce for all the people. Achievement of these purposes will save the soil, because soil conservation is an indispensable means for their full accomplishment; it is one of many inseparable aspects of the best permanent use of land. Land misuse consists of much more than permitting soil losses to occur. Its most serious manifestation is human misery; and the most serious soil losses are almost always either an effect of economic and social maladjustments or the result of a haphazard public land policy.

If this is true, the main outlines of a desirable conservation policy are clear. The Nation is blessed with more cropland than is likely to be needed in the predictable future. Half of this is in no danger, and part of the remaining half is not in great danger. As long as it is possible to meet all our needs for agricultural products by using only the land that is subject to little or no erosion, and as long as it is possible to reduce soil losses by economic and social changes desirable in themselves, a long-time policy combining both objectives is in order.

IN THE *humid areas, two of the most striking instances of soil misuse occur in cut-over forest regions and in hill regions of the East and South. In both cases rural poverty accompanies the attempt to use land that is not suited to farming. This article shows why people continue to try to make a living on poor land, and discusses some of the problems that plague these regions.*

The Problem: Land Unfit for Farming in the Humid Areas

By C. P. Barnes [1]

CUT-OVER FOREST REGIONS

SOIL MISUSE in the more recently cut-over forest regions of the Lakes States, the Atlantic and Gulf coasts, and the Pacific Northwest is less a matter of impairment of the soil itself than one of waste of human effort and of public funds. The problems of soil use have arisen largely from attempts to farm land unfit for farming (fig. 1), and from failure to make provision for continued use of forest soils for forest production.

Cultivation of soils unfit for farming is notable in the Rubicon-Roselawn, Plainfield-Coloma, Iron River-Milaca, and Ontonagon-Trenary soil areas [2] of the Lakes States. The first two of these regions have soils that are predominantly sandy in texture and generally infertile. The Iron River-Milaca and Ontonagon-Trenary areas, while they contain the more fertile soils of the northern Lakes States region, have much land that, because of stoniness or poor drainage, is unfit for farming under present economic conditions in view of the expense of clearing the land of stumps and stones.

The cut-over region of the Atlantic and Gulf coasts includes the imperfectly drained Coxville-Portsmouth-Bladen, Leon-Bladen, and Caddo-Beauregard soil areas, and the southern part of the Norfolk-Ruston soil area in southern Alabama, Mississippi, Louisiana, and Texas. In the Pacific Northwest, the Olympic-Melbourne is the principal area of cut-over forest land subject to settlement, although cultivation of soils unfit for farming occurs also in the Aiken-Konokti-Sites, the Everett-Alderwood, and the Helmer-Santa-Benewah soil areas.

Sparse farm settlement is characteristic of all cut-over regions. This is partly because of the uninviting character of large portions of the regions from an agricultural standpoint, and partly because of the

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[2] These soil areas are outlined on the soil map of the United States appearing at the end of this Yearbook.

tapering off of rapid population growth in the United States, with the consequent loss of sufficient incentive for the general occupancy of even the better portions of the regions. Some settlement has been attempted on land unfit for farming on the part of people who failed to appreciate the disadvantage that poor land suffers in competition with better land, or who failed to distinguish between land fit for farming and land not fit. Cessation of timber, sawmilling, or mining operations has caused some individuals to attempt farming poor land for lack of means or ability to acquire better land.

The consequences of this indiscriminate type of settlement have been rural poverty, excessive per capita costs of roads and schools in

FIGURE 1. An extreme case of rural poverty in the hill country.

isolated settlements, and, in the Lakes States, widespread farm abandonment. Furthermore, the failure to continue to utilize forest land for forest production has made it difficult to maintain governmental services in the face of declining tax revenue. Public debts contracted during periods when the timber constituted an important source of revenue could not be serviced from the small revenue remaining after timber exhaustion.

These problems of soil use in our cut-over forest regions are an outgrowth of traditional attitudes toward land and its use and of a tacit belief in the continued rapid growth of population in the United States. The belief that forest land has an agricultural destiny and is to be eventually cultivated was carried over from the period when forest clearing was generally followed by farming. The fact is that the demand for farm products has not increased rapidly enough to make it generally profitable to clear cut-over land for farming.

These regions furnish some of our best illustrations of the fact that proper use of the soil is not entirely a matter of good soil management

applied by farmers to the land they operate. There are many instances in these regions in which a farm, even if operated under the best possible management, would fail to provide its operator with an adequate living—indeed, in some cases, would leave him dependent on public relief.

The farming of soils unfit to farm is properly reckoned a misuse of soil. Responsibility for this type of soil misuse should not be laid wholly on the farmers. The merchants who expect to benefit by increased population, the railroad officials who wish to create more traffic, and in particular the people who trade in land, have encouraged farm settlement on land that on slight investigation would have been seen to be unsuited to farming. Even governmental bodies encouraged the settlement of poor farm land.

Cases of farmers of exceptional ability managing to live by farming poor land are sometimes cited to show that such land is in fact suited to farming and that farmers have not generally succeeded on it because of poor management. Actually, in considering whether any given type of soil is fit for farming, the assumption should be that it will be farmed by men of average, not exceptional, ability. To suppose that poor soils should be farmed because men of superior ability might farm them successfully is unrealistic. Men of superior ability do not seek poor land; they try to avoid it.

Farming of land physically unfit for farming is not the only instance of soil use that gives rise to waste in the cut-over regions. There are many areas of good soil in all of these regions, some of them large enough to support good, stable farming communities. Others are so small or so remote from other areas of good land that farms on them are widely separated from one another by long stretches of land unfit to farm. Where this is the case, many miles of road maintained for the benefit of a single family are likely to be found, pupils transported long distances to school, or schools maintained with only a handful of pupils—in short, an extremely high per capita cost of public services. Some of the so-called shoestring valleys of the Northwest, opened by the Forrest homestead law of July 11, 1906, illustrate this type of settlement. Inasmuch as the national demand for agricultural products is not so great that such remote and isolated tracts need to be farmed, these high per capita expenses do not have to be incurred by the public, and they may be said to be wasteful.

A significant contrast to the sparse settlement, rural poverty, and high per capita cost of public services so generally found in our great cut-over regions is provided by the forest region of northern Maine. A combination of circumstances has caused this region to be relatively free from agricultural settlement. Roads, schools, and other local governmental services have been practically unnecessary on account of the absence of farm settlement. Hence local governmental units have not been needed and have not been organized. Not having to support public services for the benefit of local farm settlement, taxes in the unorganized territory of Maine have been moderate, in fact, much lower than those in the organized towns. Yet this unorganized territory yields substantial public revenue derived from the productive use of its soils for the purpose to which they are best suited—the growing of forests. The revenue collected provides forest-fire protec-

tion and the few other public services needed, plus a substantial contribution to the support of government in the more populous parts of the State.

HILL REGIONS OF THE EAST AND SOUTH

Soils unfit for crops are those that would not need to be used if the relation of people to land in the country as a whole were an efficient one. The cultivation of such soils in the long-settled regions of the East and South is due originally to somewhat different causes than in the more recently settled regions, such as the Great Plains or the northern Lakes States. It is due less to failure to understand the character of land before it was settled, and more to economic circumstances that have forced the cultivation of poor soils.

Economic changes have made some of the poor soils of these hill regions unfit for cultivation since they were first settled. The competitive advantage of these soils has declined as new and more productive areas were settled farther west. The development of mechanized production has favored more nearly level areas because of lower costs of production. Erosion has probably reduced the economic advantage of some areas in the hill region, more generally than in most other regions, to a point where they are unfit for farming.

The cultivation of soils unfit for farming is widespread in the Muskingum-Wellston-Zanesville, the Hartsells-Muskingum, and the Porters-Ashe soil areas of the southern Appalachians, and in the Hanceville-Conway and the Clarksville-Lebanon soil areas of the Ozark-Ouachita Highlands in Missouri, Arkansas, and Oklahoma. It is widespread but less prevalent in the Cecil-Appling soil in the Susquehanna-Savannah-Ruston area and in the more hilly portions of the Norfolk-Ruston area in Alabama, Mississippi, Texas, and Louisiana.

In the Northeast, because of the widespread farm abandonment in the poor hill areas, cultivation of poor soils is much less common than in the hill regions of the South. It is nevertheless common in the Lordstown-Volusia, Dekalb-Lectonia, Gloucester-Plymouth, and Hermon-Colton soil areas, which include much of the highland portions of the Northeastern States.

Except in the Cotton Belt, farming on the poor hill soils of the East tends to be of a type commonly referred to as "subsistence" or "self-sufficing" farming. While greater farm production for home use should doubtless be encouraged in certain sections of the United States, it should not be thought that the subsistence or self-sufficing farms of the southern Appalachians or the Ozarks produce an abundance for those who live on them. They are subsistence farms in the sense that their cash income is so small that it is exceeded by the small production for home use. By almost any standard, the so-called subsistence farmers of the East and South are usually desperately poor. An extreme example of rural poverty is illustrated in figure 2. As poverty has increased in these areas so has the need for and use of public relief.

While a large percentage of the poor hill soils are not under cultivation at any one time, a rather large aggregate acreage has been cleared and cropped at one time or another. In the North much of the cropland abandoned was not replaced by clearing new land. In the

southern hilly regions, however, new fields very commonly are cleared to replace those depleted through a few years' cultivation. The abandoned fields may again be recleared several years later.

As in the cut-over forest regions, the exhaustion of employment opportunities in lumbering and mining has forced families to attempt to cultivate poor soils in the southern and eastern hill regions, in the absence of other means of livelihood. The densest rural settlement in any of the eastern hill regions is in the Muskingum-Wellston-Zanesville and Hartsells-Muskingum soil areas of West Virginia and Kentucky, where large numbers of persons formerly employed in the

FIGURE 2.—Futile attempts to farm soil not fit for cultivation is a common form of soil misuse in the cut-over regions. (Farm Security Administration photograph by Lee.)

bituminous coal mines left without means of support have attempted to cultivate steep and stony soils.

In the cultivation of land unfit for farming, North and South show different tendencies. In the Northeast, abandonment of farms on poor hill soils has proceeded for many years, and farm population on such soils has been steadily declining. No such pronounced tendency is generally to be observed in the hill regions of the Southern States and such areas as the Ozarks of Arkansas and Missouri. Here, population has tended to maintain itself and in some areas has increased. In the period 1930–35, a disproportionately large percentage of the increase in number of farms in the United States occurred in the southern Appalachian region on land poorly suited to farming. The differing tendencies in the two regions is doubtless attributable to the more general availability of nonfarming occupations as alter-

native means of livelihood and to the greater cost of shelter and clothing in the northeastern region.

At any rate, the occupancy of poor agricultural soils by poor people is greatest in the southeastern third of the United States, especially in the hilly portions of this region. In some of the very poor areas there is a density of farm population greater than that in the most productive parts of the Corn Belt.

The rate of natural increase in population on the poor soils of this region is materially greater than that in the country as a whole, and in farming areas generally. Unless enough people in these areas move off farms into nonfarm occupations to balance the increase of those of employable age, a rise in farm population occurs when the new generation becomes too numerous for the paternal dwellings and farms to accommodate, and an increase occurs in the number of farms.

In whatever way the cultivation of nonagricultural soils came about in the first place, its persistence must be generally explained in terms of lack of economic opportunity. People continue to farm poor land either because they do not have the means to acquire better land or because they cannot get jobs that offer them more for their labor. Poor land is cheap land and therefore available to poor people. It is, in fact, the only kind of land that poor people can generally get. A destitute family, whether its poverty be due to loss of employment in a business depression or to inadequate farm income, cannot usually acquire a home in a good farming area. Nor can the sons of farmers on poor land, seeking farms of their own, generally find opportunities to migrate to areas of better soils except as farm laborers. Good land is expensive, and the sons of poor farmers are in general no richer than their fathers. If they cannot find work in forests, mills, mines, or as farm laborers, they clear another piece of poor land and build a shack on it.

In periods of business and industrial prosperity, people tend to leave areas of poor soil and find work in nonagricultural pursuits. During the last depression, the movement out of such areas ceased, and a reverse movement of unemployed workers set in.

Over a long period of years, a net movement away from the poor farming areas in the northern part of the region has resulted in declining population. In the southern part, the net movement out of such areas has in many cases not been large enough to balance the natural increase in population within the areas; hence, farm population has not declined and in some instances has "backed up" within the areas. Even with a net migration away from farms there may still be sufficient increase in the farm population to create numbers who must either find new farms as proprietors, tenants, or laborers, or remain as laborers on the home farm. In poor areas this results in increasing cultivation of poor soils.

It is safely predictable that, so long as large sections of the general population remain impoverished, the further occupancy of poor agricultural soils in the East and South will continue. Only some very drastic measures, such as the prevention of further farm settlement on poor land by zoning or public purchase, or generous public assistance to poor people in securing good land, can be expected to prevent this occupancy of poor soil in the face of widespread impover-

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ishment. The implications of this continuing cultivation of soils not suited to farming in the hill regions of the East and South are worthy of attention.

While the ability of certain types of poor soils in these regions to provide subsistence has been demonstrated, it has been equally well demonstrated that the communities cannot provide facilities for education, communication, and health to the extent necessary for a socially satisfactory life. In almost no case have the agricultural occupants of really poor soils been able to provide themselves, through their own earnings, with good schools and roads. Because of inadequate incomes and poor communication facilities, the opportunities for individuals in poor areas to obtain secondary, vocational, and higher education are much less than in productive areas, although primary schools in some of the poor areas are provided through grants-in-aid from the States, and philanthropic agencies have in a few instances provided excellent facilities for vocational and secondary education. Unless we are willing to subsidize education in the poor agricultural areas of these regions, we may look forward to having an increasing percentage of our youth growing up with inferior educational opportunities.

Increasing density of occupation of poor soils in these regions will certainly result in a greater intensity of agricultural use. Because of increasing rural population and lack of nonfarm occupations, labor will be more abundant and cheap. More labor will be used on a given piece of land, for to impecunious people, even poor land is expensive compared to their own labor. In humid regions where a subsistence may be had from the land—in contrast to semiarid or arid regions, where farming tends to be more commercial—farms tend to be smaller where the land is poorer. There will also be more hand work, since labor will tend to take the place of capital—that is, machinery, fertilizer, etc.

Many of the poorer agricultural soils of the East and South, including some of those that are most densely occupied, are less durable when intensively cropped than are more productive soils. Some poor soil is poor for cultivated crops, not so much because it is deficient in plant nutrients as because when it is used for such crops, the soil itself begins to wash away. If soil of this character is to remain in place, either it must be covered with soil-binding vegetation, or elaborate and costly devices must be used to hold it. In this country most soil-binding cover tends to fall in the class of so-called extensive uses of land—for hay and small grains, pasture, or forest. The value per acre of production from these uses tends to be low compared with that from the more intensely cultivated crops such as corn, cotton, tobacco, and vegetables. Thus they ordinarily support fewer people per unit of area than the intensive crops. Poor people, however, are compelled to make more intensive use of the land as the density of population increases, and at the same time poorer and poorer soils come into use for intensive farming.

On fertile soil that is subject to erosion, it is generally possible, without large application of amendments, to grow cover crops or to include a valuable leguminous hay crop in the rotation, whereas on poor soil such crops can commonly be grown only with considerable use of amendments, such as lime or fertilizer.

In those hilly regions in which the poor soils are subject to erosion when intensively used, increasingly rapid reduction in productivity may be expected with increasing farm population. It is foolish to expect soil-conserving practices to be followed by people whose living, for today and tomorrow, can be obtained only by exploiting the poor soils at their disposal as intensively as they can.

It is futile to classify poor soils as unfit for farming unless it is possible to undertake the measures necessary to relieve people of the necessity of using such soils. When better economic opportunities for those who now must use poor soils can be secured, then these soils can legitimately be considered unfit for farming. It is becoming increasingly plain that these better opportunities are not becoming available through ordinary economic processes. The poor hill soils of the East and South cannot be taken out of cultivation unless public responsibility is accepted for making other opportunities available to the people who now must farm them.

PERHAPS the two things responsible for the most failure and rural poverty in the semiarid West have been human optimism over the weather and traditional eastern ideas of farming that do not fit the region. The dust bowl is an extreme result of soil misuse in this region. Yet much of the area is relatively prosperous and productive. This article considers the problems peculiar to the dry-land farming regions, the irrigated areas, and the range country.

The Problem: Subhumid Areas

By John B. Bennett, F. R. Kenney,
and W. R. Chapline[1]

THE GREAT PLAINS AND OTHER DRY-LAND FARMING REGIONS

IN THE Great Plains region repeated attempts at too intensive use of the soil have resulted in serious problems of depletion, in destruction of physical resources, in rural poverty, community instability, and heavy dependence upon outside aid.

By no means is the entire 500,000 square miles of the Great Plains region a devastated area. Much of it is made up of relatively prosperous agricultural communities and it still is the Nation's chief source of wheat. But practically all of it is affected in some degree by wind or water erosion and probably half of it has been seriously damaged. In almost half of the area a substantial portion of the farms are too small to provide an adequate living for their operators or are on land ill-suited to cultivation that should be restored to grass. On these farms economic distress is acute.

The principal cause of the misuse of the land resources of this region lies in the deceptive character of its rainfall and of its soils. The climate of the region, which stretches from the Canadian border to the thirty-first parallel in Texas, and from the Rocky Mountains to about the ninety-eighth meridian, is normally subhumid to semiarid. But the rainfall is seldom normal. It varies greatly from year to year and from month to month. At Hays, Kans., the greatest annual rainfall recorded during a 67-year period was 35.40 inches; the least, 11.80 inches, or exactly one-third as much. Even a normal annual rainfall may be so poorly distributed as to result in crop failure; a 6-inch rain may be followed by a 2-month drought.

[1] The section headed The Great Plains and Other Dry-Land Farming Regions is by John B. Bennett, Senior Agricultural Economist, in charge, Land Policy Section, Division of Land Economics, Bureau of Agricultural Economics. The section headed Irrigated Areas is by F. R. Kenney, Senior Water Utilization Economist, Division of Land Economics, Bureau of Agricultural Economics. The section headed The Range is by W. R. Chapline, Chief, Division of Range Research, Forest Service.

Rainfall tends to run in cycles. For several years it may exceed the long-time average, as in Montana during the years 1906 to 1916, and then drop below the long-time average for several years, as over the greater portion of the region since 1930. Summer temperatures and wind velocities are high, and relative humidity is usually low, so that rainfall, particularly in the southern Great Plains, is not as effective as in more humid areas.

The significant point about the rainfall of the Great Plains, however, is the fact that it varies widely about a critical point in crop production. In some portions the long-time average annual rainfall is sufficient to produce good yields of the fairly drought-resistant crops—wheat, cotton, and grain sorghums. The years of abundant rainfall produce abundant crops. But even in these areas, the crops may fail in years of subnormal or of poorly distributed rainfall. In other portions of the region, profitable crops can be produced only in years of abnormally heavy rainfall; even the rainfall of average years produces only crop failures.

The soils of the Great Plains have a superficial appearance of uniformity, particularly on the more level lands. They vary widely in their productivity, however, even within small areas. While they are generally fertile, they exhibit wide diversity in their texture, their depth, and their water-holding capacity. Almost any of them will produce fairly good crops in wet years, but in dry years only those that absorb and hold large quantities of water and resist wind erosion can be farmed successfully.

The Economic Cycle

Natural human optimism, local pride, and commercial interests that profit from new settlement and intensive land development, all exert pressure for an intensive use of the land and an accompanying commercial and social development in the Great Plains that are suitable only to the most productive soils and to climatic conditions prevailing only in the most favorable years. After a succession of years of heavy rainfall in a Great Plains community, the opinion that the climate has changed permanently for the better becomes widespread. Settlement is stimulated. Land prices rise. Range lands are heavily stocked. Large farms and ranches are subdivided to form several small grain farms. The crop acreage is expanded indiscriminately on good land and bad. New business enterprises spring up overnight. New roads and schools are built to serve the growing population, and bonds are issued on the inflated land valuations. Frequently new counties are formed, and administrative expenses of county government for a given area are doubled.

Everything goes well as long as the rains continue. But inevitably the drought years come, as with dismaying regularity they have come since 1930. The crops fail and the pasture and range grasses stop growing. Stock-water reservoirs dry up, and cattle are rushed to market to prevent them from starving or dying of thirst. The dust begins to blow and "black blizzards" lay bare the soil down to the furrow bottoms, pile drifts of dust around the farmsteads and in the fence rows, and make life unbearable for all the people within a radius of several hundred miles. With dwindling farm income, principal

and interest payments and taxes become delinquent. Mortgages are foreclosed. The local government finds it difficult to raise sufficient revenue to continue operation, and road and school bond interest payments are defaulted. The Federal Government is called upon to make emergency feed and seed loans, many of which are never repaid. Local business enterprises fail. Scenes like that shown in figure 1 are duplicated over and over again as families by the score leave the community. Many of those who remain go on relief.

At the present time large sections of the Great Plains are at the bottom of one of these cycles of heavy rainfall and expanded settle-

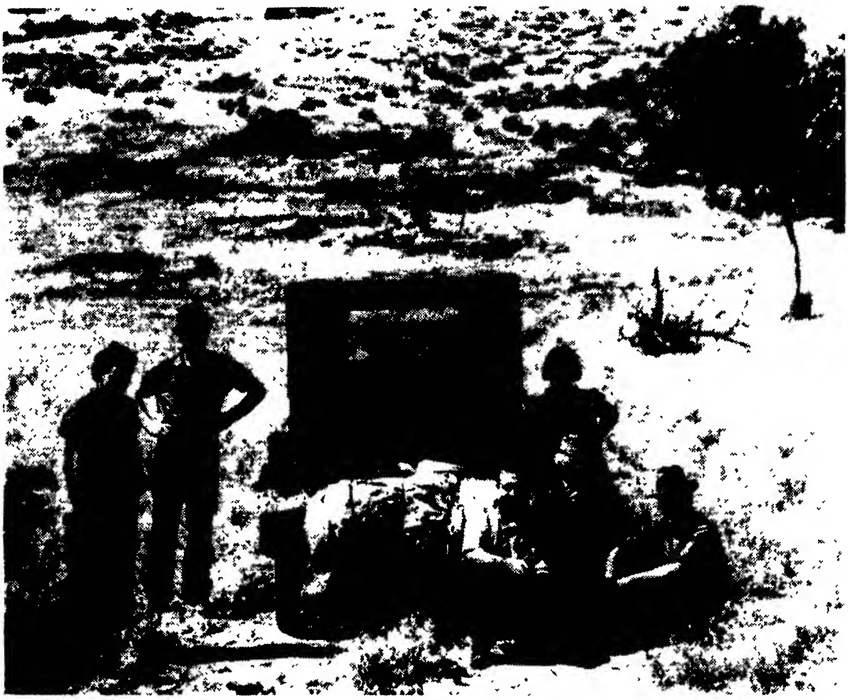

FIGURE 1. Scenes like this are duplicated many times as families by the score leave the community. (Farm Security Administration photograph by Lange.)

ment followed by protracted drought and destitution. This is the second or the third cycle for some parts of the Great Plains, for settlement in some portions of it began in the eighties. Settlement was first stimulated by the building of the transcontinental railways. It was fostered by the Homestead Acts, which granted a free quarter-section to every settler, and was given further impetus by the passage of the Enlarged Homestead Act of 1909, which provided for homesteads of 320 acres. The high prices of wheat and the patriotic drive to grow wheat during the World War exerted a great influence on the agriculture of the Plains. Wheat acreage in Montana, Wyoming, Colorado, and New Mexico between 1914 and 1919 increased from 1,361,000 acres to 4,247,000 acres. Even greater than the war prices,

however, was the influence of the tractor, the combined harvester-thresher, and large-scale plowing and planting machinery introduced during and after the war. In 1929, a decade after the close of the war, wheat acreage in the four States named above had been further expanded to 6,184,000 acres.

Undesirable Results of Land Use

Repeated attempts to base the agricultural economy of the Great Plains upon the most favorable climatic and soil conditions have had unfortunate consequences over wide areas. Ranges have been overstocked in good years and the grass has been seriously depleted in poor years. Continued cropping of lands susceptible to wind erosion has destroyed thousands of acres. Incomes have dwindled below the point where a decent standard of living could be maintained. Farmers by the thousands have left the area, many of them settling on poor cut-over lands of the Pacific Northwest or the Ozarks, or joining the ragged ranks of the migratory workers in the orchards and vegetable fields of California. Of those who have remained on their farms, a considerable portion are maintained by direct relief, work relief, or feed and seed loans. Schools have been closed or kept open only with Federal relief funds.

Misuse of the land of the Great Plains has been brought to public attention most forcibly during recent years by the dust storms, which have blanketed the country with great dust clouds as far east at times as the Atlantic seaboard. Wind erosion is serious throughout the Great Plains, except on the eastern margins of the region. In many places 3 or 4 inches of topsoil have been blown away, and in others, dunes 15 to 20 feet high have been formed. In an area covering 20 counties in southwestern Kansas, the Oklahoma Strip, the Texas Panhandle, and southeastern Colorado, a soil-erosion survey by the Soil Conservation Service showed 80 percent of the land more or less affected by wind erosion, 40 percent of it to a serious degree.

Although data on net incomes in the Great Plains region during recent drought years are inadequate to furnish any definite conclusions, it is well known from the amount of emergency credit and of work relief and direct relief funds disbursed there that incomes in the drier districts have been so low as to cause widespread distress. Even though on some of the better land the net farm income may average fairly high over a long term of years, it is likely to be so variable and uncertain as to prevent a farmer from managing his affairs effectively. C. Warren Thornthwaite, in Migration and Economic Opportunity (*128*),[2] has calculated the total net income of a 640-acre wheat farm in a western Kansas county for a 21-year period at $21,167, or a little over $1,000 a year. But of this total, $20,472 was produced in 1920, with a bumper crop at an exceptionally high price. Excluding that year, the average net income would have been about $35.

While there has been little net change in the population of the Great Plains as a whole during recent years, families by the thousands have left the drier areas. The number of families migrating from the drought areas to Washington, Oregon, and Idaho only during 1936 is

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

estimated at 8,600. Many of these have located on poor cut-over lands and have become relief or rural rehabilitation clients.

There always has been a great deal of migration into, out of, and within the Great Plains. Two-thirds of the families who lived in western Kansas in 1895 had left the area 10 years later, and by 1935 only one-tenth of them were still in the same township or still had sons living there.

Mortgage indebtedness is high in relation to the income-producing capacity of the land in the drought-stricken areas, and the refunding facilities of the Farm Credit Administration have been used widely. The Federal land banks and the Land Bank Commissioner have loaned more than $600,000,000 in the Great Plains States since 1933. Between 1918 and 1936, more than $120,000,000 in emergency feed and seed, crop, and livestock loans were disbursed in the area—about 40 percent of all such loans made in the entire country. Nearly 58 percent of these loans, which were due on December 31, 1936, remained unpaid on that date.

Economic distress in the drought-stricken areas of the Plains States has led to excessive dependence upon outside aid. Expenditures for Federal aid in the area between April 1933 and June 1936 aggregated more than $200 per capita in some counties. These included expenditures by the Federal Emergency Relief Administration, Civil Works Administration, and Works Progress Administration, Agricultural Adjustment Administration benefits and cattle purchases, and Resettlement Administration grants. Early in 1935, from 20 to 33 percent of the rural population over large areas was on relief.

Primary dependence upon real estate taxes for the maintenance of local governments in the Plains States has led to high rates of taxation, amounting in some instances to as much as 4 percent. During the drought years, rural lands have not been able to bear such taxation, and excessive delinquency has resulted. In many counties of the Great Plains 45 percent of the taxes on the 1932–33 levy were delinquent. Such wholesale delinquency has almost caused the breakdown of local government. Thousands of schools have been kept open only by Federal relief funds. In 1933–34 and 1934–35 payments of Federal funds for this purpose amounted to nearly $5,000,000.

IRRIGATED AREAS

The nature of soil misuse in irrigated areas is discussed in another section of the Yearbook.[3] Although the problem is treated there largely from a physical standpoint, the social and economic consequences of such misuse have been made clear. It is pointed out that when insufficient attention is paid to physical factors such as soil, topography, and water supply in the planning or operation of an irrigation project, failure is likely to result. The analogy of the sliding scale has already been used to show the relationship between soil productivity and economic conditions. If the market for the crop to be produced is poor, it will be inadvisable to irrigate soils of low productivity, to install a high-cost irrigation system, or to use expensive water for irrigation of that crop. Irrigation projects would seem to stand the best chance of

[3] See Irrigation in the United States, p. 693, and Soil, Water Supply, and Soil Solution in Irrigation Agriculture, p. 704.

success when all the physical factors are known and are carefully weighed in the economic balance before construction is begun.

It is difficult to arrive at a fair estimate of the extent of distress now resulting from soil misuse on irrigation projects. The 1934 Schmitt-Haw report on Federal reclamation projects, the result of a study authorized by the Secretary of the Interior, concluded that irrigation projects in general were probably in better financial condition during the depression than agriculture as a whole, and that Federal projects, largely because of the moratorium on repayments then in effect, were generally in a better physical and financial state than other projects.

The direct consequences of irrigation failure are similar to those of farming failure in general. They are seen in individual debt, impoverishment, and lowered standards of living; when an irrigation project fails, an entire community may be affected in these ways, with a resulting deterioration of community facilities. The consequences of irrigation failure are likely to be more severe than those of the failure of agriculture in general, because irrigated farming has relatively high costs. Irrigation enterprises are ordinarily community projects rather than individual enterprises, so that irrigated farming is further complicated by the problem of settlement and shares the hazards of other types of agricultural colonies.

The indirect consequences of irrigation failure may be equally serious. When irrigation bonds are defaulted or partially written off, the bondholders, many of whom are irrigators, take a loss. Defaulting on irrigation bonds affects the market for these bonds and thus hampers further irrigation development, necessary refinancing, and improvements by creating adverse capital conditions. State agencies that underwrite these bonds are seriously affected. Since some reclamation projects have been built by the Federal Government and others have been refinanced or rehabilitated by the Reconstruction Finance Corporation, the Government has a direct financial interest in the success or failure of irrigation. Poorly planned reclamation projects that involve Federal funds waste money that could be used to better advantage on more worthy projects or for other purposes. Finally, ill-advised irrigation projects affect the national economy by the inefficient use of resources. The greatest agricultural problem of the West is the relation of water to land resources. More careful planning of irrigation projects so as to bring about the use of available water supplies on good land rather than poor land would have a beneficial effect on the entire economy of the region.

THE RANGE

The 728 million acres of range land in the western United States once offered a rich heritage of fertile soil productive of ample forage—the gift of past ages. The soil received through the process of decomposition, in return for the nourishment it provided the grass and other vegetation that grew upon it, the humus and food for soil life. The result was a mellow porous surface soil, interpenetrated with roots and capable of absorbing the scant rainfall and making it available for further plant growth.

To the pioneer stockmen this extensive range area offered adventure, homes, the satisfaction of ambition, and hope of wealth. For

a time, vast livestock investments were made by eastern and even foreign capital. Herds of cattle and sheep in ever-increasing numbers were brought onto the range as more and more settlers poured into the territory. This heavy influx of livestock soon created a competition for range that reached an acute stage in many localities even before 1890.

Few users of the range realized that the conditions of low precipitation, high evaporation, recurrent droughts, and other factors constituted adverse and critical conditions under which the forage stand on range lands must grow. The average rainfall of 15 inches and less over vast acreages, for example, is far below that available on eastern pastures with which most settlers were familiar. Also, in an effort to hold what they considered were their rights on the unreserved and unappropriated public domain, nearly 150 million acres of which remained open to use by all comers until recently, and to discourage new settlers, many stockmen turned their livestock onto the range in the spring before growth was sufficiently advanced to withstand grazing without injury and kept such large numbers of livestock that the herbage was excessively grazed and the soil trampled. Some even believed it worth while to maintain seriously depleted conditions to keep others out.

As the more palatable grasses lost their vigor and productive capacity under overgrazing, the livestock were forced to turn to the less palatable plants, and these in turn were weakened. On extensive areas such palatable grasses as bluebunch wheatgrass and ricegrass have largely or entirely disappeared. On other areas the stand of other palatable perennial grasses and herbs has been thinned and partly replaced by annuals, weeds, and shrubs of low feeding value.

With a thinner stand of vegetation, especially of grasses, and a trampled and gradually deteriorating soil, little vegetable matter remains after heavy grazing to build the soil or to check run-off. Less of the rainfall is absorbed by the soil, and the more rapid run-off resulting carries away the humic material and more fertile topsoil. The productive capacity of the soil is consequently lessened, and the reduced amount of forage is grazed more closely by the livestock in an effort to obtain food. Thus the vicious circle of depletion of forage and soil and of overgrazing continues on the western range.

On the average, the range area now shows a depletion in its grazing capacity of 52 percent, and 575 million of the 728 million acres are more or less depleted. The area recently organized into grazing districts and that remaining in the unreserved and unappropriated public domain, representing the least productive lands and the most critical type of growing conditions, are in the worst state, having an average depletion of 67 percent. The condition of most of the 375 million acres of privately owned land too commonly reflects the emphasis placed by users and their financial backers on numbers of animals grazed rather than on amount and character of production from the herd. Too often a stockman making a small profit from his herd increases the number, without regard to past or future depletion of the range, in an effort to obtain a maximum current return to meet high interest rates and overinvestment in lands and livestock. The privately owned range has been overstocked, and some 85 percent

of the area is depleted over 50 percent, on the average, in grazing capacity.

Drought is the joker in sustained forage and livestock production. Stockmen are apt to consider drought as an unusual occurrence. Actually, on large areas in the West, in 3 or more years out of every 10, the rainfall is at least 25 percent below average, a deficiency that ordinarily seriously hampers forage production. With a critical balance existing under normal climatic conditions between the survival and death of plants on western ranges, and with this balance easily upset in drought years if the range is even slightly overused, palatable vegetation readily dies out. For example, ricegrass, one of the most important perennial grasses of the winter ranges of western Utah, lost almost 90 percent of its stand under heavy grazing, and winterfat, a palatable browse, lost over 50 percent. Similar heavy losses were found to have occurred in 1935 on overgrazed ranges in other parts of the West as a result of the 1934 drought. One of the primary causes of such serious depletion is the failure to stock ranges below their average grazing capacity as an insurance against drought or to adjust stocking promptly to the drought declines.

The widespread depletion and the unsound management that normally accompanies this condition have had serious social and economic consequences. The livestock industry has failed to make the profit to which it is justly entitled. More and more the industry has been forced to augment its depleted natural range forage with more costly farm-raised supplemental feeds. This is illustrated in the results from experimental pastures at the United States Range Livestock Experiment Station, near Miles City, Mont., in studies handled by the Forest Service in cooperation with the Bureau of Animal Industry and the Montana Agricultural Experiment Station. In the 4 years 1933–36 a herd of 20 breeding cows on range approximately 25-percent overstocked produced an average calf crop of 72.5 percent and an average annual weight of calves prorated to all cows of only 180.4 pounds. A herd of 20 breeding cows on comparable range moderately grazed produced an 85-percent calf crop and a calf weight of 249.6 pounds per cow annually, a gain of more than 38 percent in favor of proper stocking. Shortage of range feed during the drought of 1934 made heavy supplemental feeding necessary. On the overgrazed range the average annual cost for range and hay was 6.21 cents per pound of weaning calf weight, in contrast to 3.87 cents per pound on moderately grazed range.

As a result of this depletion, 80 percent of the entire range area, or some 589 million acres, is eroding more or less seriously, thus reducing the productive capacity of the soil. Nearly half of the area is contributing silt in disturbing quantities to major western streams, thus impairing their value for irrigation, power, and municipal water supplies. Floods are increasing in number and destructiveness, leaving in their wake ruined farm land and damaged homes and other property. Recreation and wildlife production have been impaired. Many streams, once abounding in fish, now are so subject to floods and so silt-laden that their value for fishing is nil. Winter ranges of big game have been curtailed and feed production on them is often scarce,

resulting in serious starvation losses or the necessity of supplemental feeding of wildlife, an undesirable practice.

The successive waves of failures, the reduced standards of living, defeated hopes and ambitions, abandoned homes, closed schools and churches, widespread tax delinquency, and large acreages reverted to counties and States, furnish an indication of the effect of unrestrained exploitation and range destruction on social well-being.

That such conditions need not prevail is shown by the results obtained on the numerous well-managed private ranges and on the national forests, which are administered with a conservation objective in mind and are used for livestock grazing by more than 25,000 local settlers and ranchers. Those stockmen who have not misused their ranges are the ones who have remained in the livestock business through droughts and depressions as well as during good years and who have, over the years, made a reasonable living from their business.

DRAINAGE of farm land has made many prosperous communities where agricultural production was formerly severely handicapped or impossible. But under conditions of temporary prosperity, it has also been applied to soils not suited to farming. As this article shows, the results in such cases are evident in delinquent taxes, heavier debt, lower standards of living, and the wiping out of wildlife that would pay much better than the mistaken effort to cultivate unsuitable soil.

The Problem: Drained Areas and Wildlife Habitats

By F. R. KENNEY *and* W. L. MCATEE [1]

LARGE AREAS of land have been made available for agricultural production by drainage projects. Farm drainage has improved the productivity of other lands. The 1930 census indicates that in 1929 there were more than 84,000,000 acres of lands in drainage enterprises in the 35 States where drainage was important. Of this, 63,000,000 acres was improved land.

Much of this land has proved to be well adapted to agriculture, and prosperous communities have resulted from its cultivation. Some of it, however, is not suited to crop production, and on such of this as was settled farming proved to be unprofitable, and either the land was abandoned or the farm operators live in a state of distress. In 1930, drainage taxes were delinquent on 30 percent of the drained area. Payments on principal or interest on bonded indebtedness of the enterprise were in arrears for 12 percent. More recent data are not available, but since the depression the proportion of land with taxes delinquent or in arrears has undoubtedly increased.

Some of the drained lands have never been settled. The 1930 census shows that nearly 9,000,000 acres of land in drainage enterprises was available at that time for settlement. Although part of this land cannot be profitably farmed without additional farm drainage, the large amount of land for which at least partial drainage has been provided and which is not settled suggests heavy losses in drainage expenditures.

One of the major causes of difficulties encountered by drainage enterprises has been the drainage of lands having soil unsuited to agricultural production. Land that has been drained without first

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determining the fitness of the soil for crops has too often been found to be unsuited to farming. In some cases the soil of drained areas is peat, which could not be profitably farmed. Moreover, after the peat became thoroughly dry it presented a dangerous fire hazard. Peat fires on drained lands in several parts of the country have entirely destroyed the topsoil down to impervious clay or rock, leaving the land practically worthless for plant life.

An example of uneconomic drainage of swamp lands is found in parts of Minnesota. Under the stimulus of a wave of settlement and land speculation, large swamp areas in northern Minnesota were drained. State and Federal laws were passed to further reclamation by permitting the assessment of unreclaimed public land in drainage districts, and the State entered actively into the construction of drainage works. Much of the land reclaimed was never settled, and other land was abandoned because it was not productive enough to bear the cost of reclaiming it. County governments in some cases have been unable to retire drainage bonds coming due. By 1934 the State of Minnesota had spent $4,000,000 in aiding distressed districts. Other losses also resulted. According to a report by the Minnesota State Planning Board: "The disastrous fires in the Red Lake territory in 1910, 1918, and 1931 can be traced directly to the desiccation of these normally wet areas."

*Another of several examples occurred in Florida, where much of the land drained during prosperous times proved to be unsuited to agri-*culture. When the artificial prosperity subsided, land was abandoned and the remaining farmers were forced to carry the cost of the entire enterprise.

Uneconomical drainage has a direct effect on the farmer, impoverishing him or placing him more deeply in debt, and lowering his and his family's standard of living. Where an entire drainage project fails or falls into financial difficulties, whole communities may be similarly affected. The savings of bondholders are destroyed, and the lack of confidence engendered by the failures makes the financing of worthy drainage projects more difficult. In some instances local or State governments as well as private investors have sustained heavy losses.

Not only have ill-advised projects caused distress to those directly connected with them, but areas suited to wildlife and to the retardation of floods have been spoiled for these uses. Drainage often lowers the water table in the vicinity of the project. Where the drained land can be put to a useful purpose the benefits usually outweigh the disadvantages; otherwise, a double disadvantage accrues.

Among the assets of mankind, wildlife receives its true appraisal only in advanced stages of civilization, when, owing to the heedless destruction of earlier times, it has been seriously if not irreparably reduced. Under pioneer conditions the rules for the treatment of wildlife are immediate exploitation of the useful and drastic destruction of the useless, and these rules tend to remain in effect long after the original motives are gone. In the earlier stages of settlement no one thinks of allotting any land for the use of wildlife; the effort is to wrest every possible acre from nature and make it yield an income. There is no vision to see, there is no time to learn, that land units with their natural occupants, as exemplified by a beaver meadow, a

muskrat marsh, a duck lake, a deer forest, or an antelope mesa, are productive entities that under certain circumstances may be worth far more than anything man can put in their place and that once destroyed may never be reestablished.

If we had sufficient foresight we would preserve in due proportion nature's wealth-creating centers of every kind, but lacking it we are wasters. Experience at last brings regret, and we would re-create what we have destroyed. We see that it has values that we can ill afford to lose, not only in a material sense but for beauty as well.

When at length we do realize what nature's bounties mean to us we should act promptly, positively, and persistently in maintaining and restoring them. We have been slow in taking wild life into consideration in the allotment and utilization of land, but nationally the movement began with the closing of Yellowstone Park to hunting in 1894, creation of the first Federal bird refuge (Pelican Island, Fla.) in 1903, and of the first national big-game preserve (Wichita, Okla.) in 1905, and it has continued with ever-growing momentum.

Despoliation has affected almost every kind of wildlife habitat, but the process has perhaps been most conspicuous and most harmful in relation to aquatic environments. Drainage, diversion, and pollution have been the principal means of destruction, but of these only the first two have a substantial relation to land use.

Drainage is beneficial to farming in so many ways that any possible disadvantages are often overlooked. While it has been an accepted and well-nigh universal farm practice, experience has taught that it is not everywhere and at all times wholly desirable. It is one of those things that have to be lived with to be thoroughly understood. Especially is that the case in regions where occasional very dry seasons or series of dry seasons occur. When the dry time comes man learns what he should have foreseen, that water is a most precious commodity, one that should be hoarded in times of plenty as a buffer against disaster in times of need. Drains installed to carry water away do it just as effectively when there is a shortage as when there is plenty of rain or snow. If precipitation does not continue in great enough volume to offset losses by evaporation, transpiration, and drainage, all watering places for stock may go dry. It is in such dry times that the farmer may lose to every wind loads of the precious topsoil of his fields, which no longer can maintain the plant cover that alone could hold it in place.

One of the prime factors in reducing the waterfowl population of our continent was the drainage, chiefly in the northern Great Plains for wheat farming, that destroyed many of the most productive breeding places of these highly valuable birds, both in the United States and in Canada. Drought has now shown us that drainage of that region was carried on to a degree harmful even to the direct interests of man and that it would have been well to have left a great deal of this territory in its original undrained condition.

On a lesser scale, wildlife has been damaged by the drainage of small marshy and swampy tracts on farms. These were essential habitats for such fur animals as the muskrat and the mink and afforded attractive feeding, watering, and resting places for a variety of other forms of wildlife, some of which also are fur bearers. A great part of the fur

crop of the country comes from farms, and harvesting it yields an annual income of many millions of dollars. It is safe to say, however, that only a small share of that income accrues to the residents of thoroughly drained farms.

Much drainage has been done that should never have been undertaken, but if we will, we can use foresight to avoid similar mistakes in the future. Furthermore, there is merit in attempting to reclaim drained lands and to increase water impoundment wherever practicable. The widespread development of farm fishponds and stock-watering places is evidence of a change in sentiment about doing away with water. In the Dakotas, particularly, the lesson of drought has been taken to heart, and dams for holding water supplies have been and are being built by the hundreds wherever practicable. The Bureau of Biological Survey is participating in this movement in cooperation with the Works Progress Administration and landowners.

For the sake of getting water impoundments on their properties, owners have gladly granted easements conveying to the Government in perpetuity rights to protect wildlife, to impound water, to fence, to erect refuge markers, and otherwise to develop the areas to make them habitable and attractive to migratory waterfowl. In the fiscal year 1936, 32 easement refuges were established in North Dakota, comprising in all 57,932 acres and impounding water on 27,325 acres. In the fiscal year 1937, 43 additional refuges of this type were obtained (39 in North Dakota and 4 in Montana), bringing the total acreage for this class to 118,775, nearly half of which is covered by water. These projects not only constitute a very desirable supplement to the system of large waterfowl refuges but are of recognized importance in an absolutely necessary water-conservation program (figs. 1 and 2).

In Minnesota, before Thief and Mud Lakes, formerly famous waterfowl resorts in Marshall County, could be restored, it was necessary to get a special enabling act from the State legislature. Under authority of that act, passed in 1929, the Minnesota State Conservation Commission has restored Thief Lake (about 7,000 acres), and the Federal Bureau of Biological Survey, Mud Lake (about 5,000 acres). In each case, surrounding marshlands have been improved, so that the areas available for wildlife are considerably greater than the figures cited would indicate. The Mud Lake Refuge, for instance, comprises some 52,000 acres.

On Lake Mattamuskeet in North Carolina, about 50,000 acres was so low-lying that pumping was tried in an effort to dry it sufficiently for agricultural use. An expensive system of dikes and an elaborate pumping plant were installed, but the project was never a success during several years of trial. Originally the lake was an important resort for swans, geese, and other waterfowl, and now as a Federal refuge it has been restored to the use of these birds. A haven such as this is absolutely necessary to the conservation of the greater snow goose and of the whistling swan, virtually the entire populations of which winter on a restricted stretch of the Atlantic coast from New Jersey to North Carolina.

Drainage, pumping, and excluding water are means that have been used to destroy large areas of the finest habitat this country afforded for waterfowl. Destruction of the habitat also destroyed the birds,

because it deprived some of the most important colonies of the opportunity of reproducing themselves. Where, as in so many cases, the so-called reclamation was accomplished at great expenditure of funds with no adequate return, truly the effort was not worth while.

Important areas other than those already mentioned, but like them characterized by maladjustment of water relations, that have recently been restored by the Biological Survey, include the Spalding ranch,

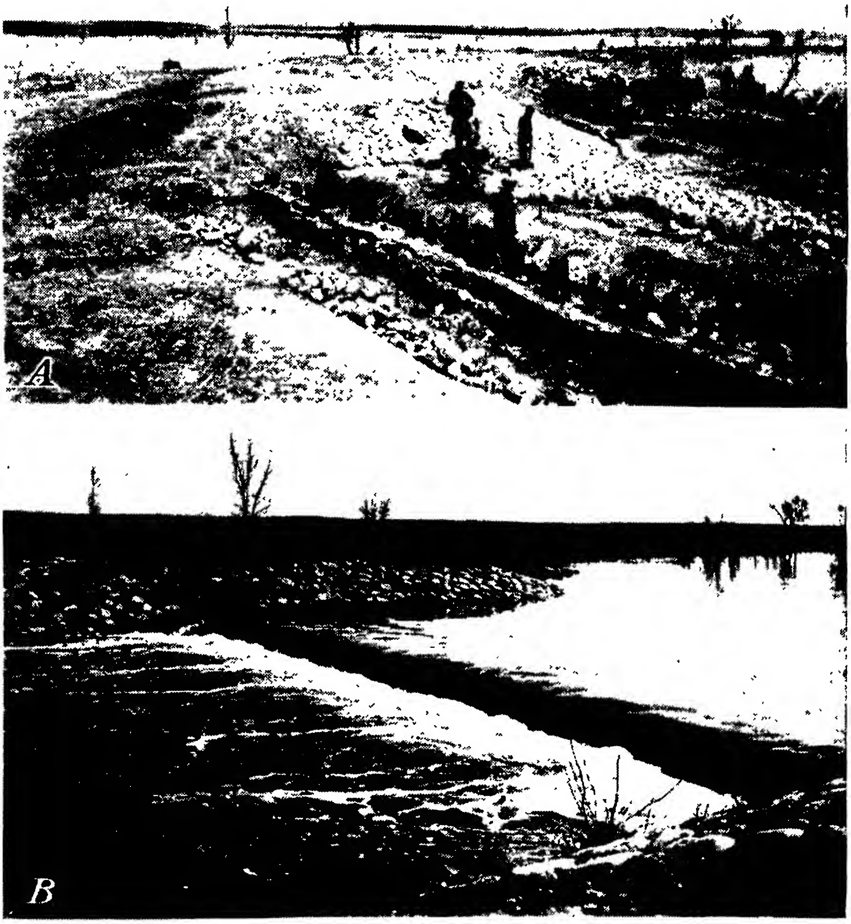

FIGURE 1.—*A*, View of dike- and spillway-construction work, Lake Tewaukan migratory-waterfowl project, southeastern North Dakota, showing dry lake bed and finishing touches on stone facing of dikes; *B*, view from same point, 1 year later when the new lake, covering 1,436 acres, made an attractive resting place for migrant ducks and geese and a nesting site for mallards, pintails, teals, canvas-backs, and other ducks.

Sacramento Valley, Calif. (10,775 acres), Seney marsh, Michigan (85,802), Lower Souris River flood plain, North Dakota (59,028), Blitzen River Valley, Oreg. (65,402), and Lake Malheur, Oreg. (46,000)

Where restoration is required, it is evidence in every case of one of man's greatest failings—his inability or unwillingness to profit by experience. If it could be decided in advance whether an area had best be preserved as lake, marsh, or swamp, it would not be necessary to go through the expensive and wasteful process of draining and trying to farm the tract in order to be convinced. Fortunately, technical organizations can in part at least prevent such mistakes by determining whether a wet area may not serve its highest use if preserved in its natural condition.

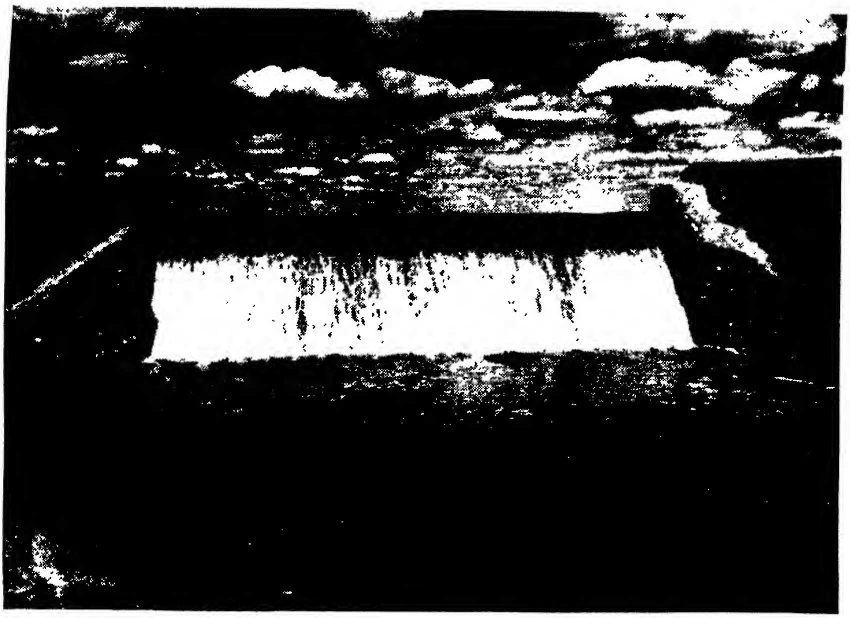

FIGURE 2.—Spillway of lake created by a dam and dike on the Wildfang migratory-waterfowl project, central North Dakota—view taken in June 1937, shortly after a heavy rain. Formerly the nearest water area was 25 miles distant; now there is water enough for all. This water impoundment is typical of improvements on easement refuges.

Among the larger reservations of relatively unspoiled areas that have recently been made in the course of the campaign for restoration of migratory waterfowl are the White River swamp country, Arkansas (110,000 acres), Okefenokee Swamp, Ga. (296,000), the Cameron County coastal marsh, Louisiana (137,233), the lake-dotted sand hills of Nebraska (109,071), and the Cape Romain salt marshes and sand islands, South Carolina (62,254). Up to June 30, 1937, 220 areas totaling 6,464,147 acres had been reserved primarily for Federal bird-refuge purposes—good evidence that in this direction the Government is now taking due account of wildlife in land-use planning and land utilization.

Nor is upland wildlife being neglected. In this case as in that of the waterfowl, great abuse of animals and of their rightful habitat resulted from man's persistence in following so largely the trial-and-error system of learning. For example, the Charles Sheldon and Hart Mountain antelope ranges in northwestern Nevada and southeastern Oregon are ideal for the maintenance of antelope but unfitted for permanent commercial livestock production. They should have been reserved for antelope and their desert associates from the beginning. Fortunately, that fact was realized before it was too late, and now more than 835,000 acres of range have been set aside, enough to assure the perpetuation in that section of the antelope, the mule deer, and other characteristic wild mammals, as well as birds and native plant life. Other areas have been reserved for the protection of important herds of buffalo, elk, and bighorn sheep. The number of Federal big-game preserves and ranges in the United States (excluding territories) on June 30, 1937, was 10 and their aggregate acreage 3,907,227.

The creation of large public reservations is not the only way in which land can be restored to the uses of wildlife and to the benefit of the Nation. Almost every farm has unused portions that can well be dedicated to wildlife. The services of the wild inhabitants in keeping the balance between injurious and beneficial organisms on the farm, and the meat and fur values of the larger animals particularly, will repay the farmer for his care. Owners of fishponds and muskrat marshes do not need to be told of the advantage of keeping them in productive condition, but suitable places not now productive can be added to the number of well-managed tracts of this character, and entirely new ones can be made. The fortunate possessor of a beaver meadow can guard it zealously as a source of income and, like all impoundments of water, as a means of preserving the groundwater supply and of aiding in erosion control.

Tracts of land devoted primarily to growing trees or other crops or to public recreation also can often be partially dedicated to wildlife production and thus gain in value to the Nation. Wildlife is worth some hundreds of millions of dollars annually, and this return can be maintained and even increased by giving it proper consideration in land planning.

With the adoption of a program of land use, certain remedies must be applied specifically to uneconomical drainage. A program for the restoration of marshes through the plugging of ill-advised drainage ditches must be evaluated. This type of work has already been done in many instances. In Minnesota the Farm Security Administration (formerly the Resettlement Administration) has been re-creating peat bogs by plugging up drainage outlets, and at the same time has been aiding stranded settlers to move from the submarginal land. The Biological Survey, by means of similar checks and dikes, has been restoring other overdrained areas to natural marsh conditions, thus creating refuges for migratory waterfowl.

One means of protecting communities from the effects of undesirable drainage would be to empower State drainage commissions to refuse charters to drainage districts that propose the drainage of submarginal land. Necessary control of this type will depend upon the determination of submarginal areas by a comprehensive program of land classification.

WHAT is the nature of the soil losses resulting from cropping, leaching, and erosion in the United States? What is the extent of the losses by erosion? What are the effects of these losses on crop yields? How much land can be safely cultivated under present practices and under improved practices? To what extent do erosion losses offset the improvements in agriculture in modern times? What are the effects of soil erosion in increasing floods, on sedimentation of navigable streams, and on water conservation? These questions are both vital and difficult to answer, but this article attempts to answer them in the light of the measurements and estimates available.

The Problem: The Nation As a Whole

By E. J. Utz, Charles E. Kellogg, E. H. Reed, J. H. Stallings, *and* E. N. Munns [1]

THE NATURE AND EXTENT OF SOIL LOSSES [2]

SOIL is useful to man because of its capacity to produce the plant he needs for food and shelter. This capacity is associated with certain internal characteristics of composition and structure that have developed with the soil and may be injured or improved when man uses it. The changes in the soil that decrease its productivity for crop plants may follow from three processes—cropping, erosion, and leaching. They may adversely affect the physical condition or the chemical composition of the soil, or both.

Lower productiveness does not necessarily follow when land is put to agricultural use, although it has occurred in many soils of the United States. Good management, including the use of rotations and necessary fertilizers, will permit maintenance of and even increases in the productivity of soils adapted to cultivation. Such increases have occurred in many soils in the United States. These soils are subject to certain losses of plant nutrients in crops and deterioration of structure through cultivation, but such losses are offset in

[1] The section headed The Nature and Extent of Soil Losses is by E. J. Utz, in charge of Erosion Control Practices, Division of Conservation Operations, Soil Conservation Service, and Charles E. Kellogg, Principal Soil Scientist, Bureau of Chemistry and Soils. The section headed Effect of Soil Losses on Crop Yields is by E. H. Reed, Senior Soil Conservationist, Soil Conservation Service. The section headed The Effect of Soil Erosion on Floods, Navigation, Water-Power Development, and Water Conservation is by J. H. Stallings, Senior Soil Conservationist, Soil Conservation Service, and E. N. Munns, Chief, Division of Forest Influences, Forest Service.

[2] The authors wish to acknowledge the assistance of Roy W. Simonson of the Department of Soils, University of Wisconsin, and M. H. Cohee, Senior Soil Conservationist, Division of Conservation Operations, Soil Conservation Service.

current farm practices. On the other hand, soils over large parts of the Great Plains and in other regions are less productive than they were when first plowed. Various explanations have been proposed for the declining productivity, but the basic reason in all instances is an unwise use of the land. Current practices may have neglected the effect of cultivation on the structure of the soil, as in the Great Plains, or may have made no provision for the return of plant nutrients lost in crops. In either case, decreased productivity will follow and the soil will become susceptible to further losses through accelerated erosion. Serious soil losses will eventually follow from continued misuse of the land or wherever fertility and structure are not maintained.

Nature of Soil Losses

Soil losses, in a broad sense, will include all changes that result in a decreased productivity for crop plants and may be grouped under two general heads— physical and chemical. Physical losses, as the term is used here, will refer to changes in the physical condition of the soil rather than to physical removal of the soil itself. Loss of structure or changes in structure are the principal physical losses and may be brought about through cropping or erosion. Chemical losses include all removal of soil constituents, either as nutrients in crops or as salts in drainage waters, as well as removal of the soil itself through erosion. Physical and chemical losses seldom occur separately; loss of structure is accompanied by removal of plant nutrients in crops or loss of a part of the soil through erosion.

Changes in Physical Condition

The grouping of the individual particles within the soil mass is referred to as soil structure. A variety of groupings is possible and quite a number occur, but certain ones are much more favorable for the growth of crop plants than others. The granular condition of the dark-colored soils of the grasslands when first plowed is one example of a highly desirable structure that develops under a close-growing type of vegetation such as grass. A more common type of favorable soil structure, particularly in humid regions, is a crumb condition in which the aggregates are less uniform in size but somewhat more friable.

A desirable structure may be destroyed either by long-time cultivation or by erosion. Long-time cultivation is usually, but not always, necessary for deterioration of structure. Plowing of heavy clay soils when wet often brings about an immediate cloddy condition unfavorable to plant growth. Generally speaking, however, decreases in the granulation of a soil through cultivation are so small from one year to the next that many years are necessary before the effects become serious. Tillage breaks down granulation without actual removal of soil, whereas erosion accomplishes deterioration of structure by removal of a friable surface horizon overlying a less friable subsoil. Changes in structure due to erosion ordinarily do not take place until the land has been cultivated for a period of years or where grasslands have been seriously overgrazed, after which deterioration of structure may occur rapidly or very gradually.

Changes in soil texture [3] may accompany or follow deterioration of soil structure; they do not occur independently. In arid regions, wind may carry away the silt and clay particles from the surface soil to leave small hummocks of sand scattered here and there, but deterioration precedes actual removal. In humid regions, erosion of a lighter surface horizon overlying a heavy subsoil may bring about a change in texture. The influence of texture on plant growth is largely associated with its effect on the structure or degree of granulation of the soil.

The influence of soil structure on soil productivity has not received the attention that it deserves in the United States except in extreme instances. Research workers as a group have been much more concerned with the supplies of nitrogen, phosphorus, water, and the like in soil than with its structure. All of these factors are important and merit study, but not any more than does structure. The structure of a soil largely determines its permeability to water and plant roots, its capacity to retain moisture and release it to growing plants, and its resistance to erosion by wind or water. Such properties are fundamental to continued productivity.

Losses of Plant Nutrients

Chemical losses, or the actual removal of soil constituents, may occur through one or more of the processes of cropping, erosion, and leaching. Significant losses of nitrogen from the soil through volatilization may also occur under conditions of poor drainage. The removal of soil constituents in crops is greatest on cultivated soils, but occurs on all lands from which man harvests crops, trees, or grass, including grazing lands. Losses due to removal of plants are serious, however, only on cropped or heavily grazed lands. Erosion by water may take place wherever there are losses of water through run-off, but these losses are appreciable on sloping lands and particularly on sloping cultivated areas. Wind erosion takes place irrespective of slope. A certain small amount of erosion is necessary if soils of humid regions are to remain productive. Accelerated erosion, which usually follows when soils have been misused or have suffered an appreciable loss in their original fertility, brings about the serious physical and chemical soil losses. Leaching occurs on all soils in humid regions and to a limited extent on soils of semiarid regions. Sufficient leaching to remove soluble salts is necessary for the maintenance of productive soils, but some of the losses, such as that of nitrogen, are not desirable and can be controlled through the use of cover crops.

Of the various elements that make up the soil, 14 are generally recognized as being essential for plant growth. Plants obtain all but one or two of these elements directly from the soil and can utilize those from no other source. All of these elements are subject to removal from the soil to some extent, but not all of the losses become critical. Generally speaking, the loss of four elements—phosphorus, nitrogen, potassium, and calcium—becomes serious. These four elements do not exist in similar amounts in all soils, nor are they lost at similar rates. Soils generally contain more calcium than nitrogen; less phosphorus than potassium. Crop plants commonly remove more nitrogen than

[3] Soil texture is determined by the relative proportions of sand, silt, and clay present in the soil.

calcium, leaching more calcium than phosphorus. The amounts of plant nutrients lost from any one soil will depend upon the quantities present and the particular combination of processes operating on that soil.

On any cultivated soil in the humid region, cropping, erosion, and leaching, either singly or in combination, are responsible for soil losses. In semiarid and arid regions, only erosion and crop removal will be of importance.

Soil Losses Through Cropping

A number of estimates of amounts of plant nutrients removed from the soil by crops have been prepared from data on composition and yields (*226*, *331*).[4] One such group of figures, for a Dunkirk silty clay loam at Ithaca, N. Y., (*226*) shows average amount removed annually under a standard rotation [5] to be as follows:

	Pounds per acre		*Pounds per acre*
Nitrogen	60	Calcium	30
Phosphorus	25	Magnesium	20
Potassium	50		

The larger losses of nitrogen and potassium will be noted. Similar trends appear in other estimates of cropping losses in humid regions, although the amounts given for actual losses of the separate elements may differ widely. Different crops require differing amounts of the various elements, and one crop may differ in its uptake of minerals from one year to the next. For example, legumes require more phosphorous than small grains, and a 20-bushel crop of wheat will take more nitrogen than a 10-bushel one. Actual removal of plant nutrients in crops will depend upon the types of crops grown and the yields obtained.

Soil Losses Through Leaching

Losses due to leaching have been estimated from lysimeter studies, and they have been calculated from the content of salt in river waters. Data obtained with lysimeters at Aberdeen, Scotland, and Ithaca, N. Y., are given in table 1 (*226*). The Aberdeen data are included because they are part of the few available for undisturbed blocks of soil. The soils themselves are not strictly comparable to those of any extensive areas in the United States.

Table 1.—*Average annual losses per acre of nutrient elements in drainage waters*

Locality and treatment of soil	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Aberdeen, Scotland, Craibstone lysimeters					
Untreated (6 years)	6.7	(1)	10.6	69.6	25.5
Complete fertilizer plus lime	6.9	(1)	9.2	111.4	31.2
Ithaca, N. Y., Cornell lysimeters; Dunkirk silty clay loam (10 years):					
Bare	69.0	(1)	86.8	557.2	104.4
Rotation	7.8	(1)	69.1	322.0	73.2
Grass	2.5	(1)	74.5	364.0	81.3

[1] Trace.

[4] Italic numbers in parentheses refer to Literature Cited, p. 1181.

[5] A standard rotation would probably be one for 5 years and would include corn, oats, wheat, and clover and timothy (2 years).

The large loss of calcium and the negligible loss of phosphorus are evident in both sets of data; similar conditions will prevail generally in the upland soils of humid regions.

Of special interest is the much greater loss of nitrogen from the Cornell lysimeters when the soil is bare. It immediately suggests the value of a cover crop wherever soils are subject to much leaching. Cover crops use the nitrogen that would otherwise be leached away, and they can later be turned under as green manure. In addition to reducing losses of nitrogen by leaching, cover crops may aid in preventing erosion. Soils that are permeable enough to be subject to serious leaching losses are seldom subject to water erosion, but it does not follow that they may not be subject to erosion by wind.

Soil Losses Through Erosion

Soil losses from erosion are commonly stated as tons of soil lost per acre. Estimated removal of nutrient elements, if desired, is then calculated from previous analyses that may be available. More information can be gained, however, by comparing the composition of the surface soil before and after erosion. The tons of soil lost may or may not have been productive for crop plants. Soils of low productivity, either because of steep slopes or low inherent fertility, are more subject to erosion than soils that are highly productive and support a dense vegetative cover. Data for the partial composition of eight soils selected from various parts of the United States to illustrate conditions in the principal soil groups are given in table 2.

Table 2.—*Partial composition of soils from various parts of United States by 1-foot sections* [1]

Soil series, group, and location	Depth	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Feet	*Pounds* [2]	*Pounds* [2]	*Pounds* [2]	*Pounds* [2]	*Pounds* [2]
Beltrami silt loam, Podzol, Minnesota	1	1,200	3,600	84,000	70,000	35,200
	2	2,800	5,600	98,800	84,800	81,600
	3	1,600	4,800	76,800	391,600	160,800
Muskingum silt loam, Gray-Brown Podzolic, Ohio.	1	4,400	2,000	90,800	18,000	3,600
	2	1,600	1,600	115,600	10,800	11,800
	3	1,600	400	111,600	8,800	2,000
	4	1,600	400	118,800	9,200	2,400
Cecil sandy clay loam, Red Podzolic, North Carolina.	1	2,800	5,200	22,000	12,000	12,800
	2	1,600	5,600	23,600	11,200	11,600
	3	1,600	5,200	19,200	10,800	11,200
	4	1,600	5,200	17,200	10,400	11,200
Norfolk fine sandy loam, Yellow Podzolic, Georgia.	1	2,000	800	2,400	14,400	4,800
	2	1,200	1,600	2,800	14,000	6,400
	3	1,200	1,200	1,200	12,000	6,400
	5	400	6,000	2,000	5,600	4,000
Shelby silt loam, Prairie, Missouri	1	5,600	11,600	58,000	34,800	36,800
	2	3,200	9,200	56,400	50,000	46,400
	3–4	1,200	18,000	55,800	282,000	46,000
	5	800	12,000	55,400	269,600	41,200
Barnes silt loam, Chernozen, South Dakota	1	11,800	72,000	76,800	55,200	37,600
	2	2,800	40,000	78,800	74,000	48,400
	3	800	60,000	60,400	384,400	100,800
	4	800	60,000	60,800	377,200	100,800
Rosebud silt loam, Chestnut, Nebraska	1	2,800	48,000	112,800	70,000	46,400
	2	2,000	48,000	114,400	158,800	49,600
	3	2,000	52,000	122,800	176,800	64,000
Mohave loam, Red Desert, Arizona	1	800	68,000	106,000	91,200	60,800
	2	400	64,000	82,400	422,000	63,200
	3	400	68,000	72,000	642,800	64,000
	6	0	60,000	87,200	119,200	43,600

[1] Original data from Atlas of American Agriculture (*240*) and from various technical bulletins of the Division of Soil Chemistry and Physics, Bureau of Chemistry and Soils.
[2] Pounds per acre. 1 acre-foot assumed to weigh 4,000,000 pounds.

It will be noted in table 2 that the content of nitrogen decreases with depth in all soils but one and that calcium, potassium, and magnesium are often present in greater quantity in the second foot than in the first. The quantities of the various elements, other than phosphorus, available for growth in the 1-foot sections will be roughly proportional to the total amounts present. The amounts of phosphorus available to plants in the different soil layers will depend upon the content of humus, iron oxide, alumina, and lime quite as much as on the total content of phosphorus. Subsoils will normally contain less available phosphorus because they contain less humus and often more iron oxide, alumina, or lime. Considering the soils of the country as a whole, there will be less nitrogen and available phosphorus in the subsoil, but there will be as much or more calcium, magnesium, and potassium. Serious losses of nutrient elements through erosion, therefore, will be of nitrogen and phosphorus.

Significance of Various Losses

Mention has already been made of the importance of soil structure to continued productivity. A desirable structure is just as important as a high level of fertility; one without the other is of little value. Soils that have developed under grass originally possess a very desirable structure and will retain it for a long time under cultivation if proper cropping practices are followed. Close-growing crops like the grasses and legumes must be included in a rotation if a favorable soil structure is to be established or maintained.

It is generally more difficult to recover a favorable structure than it is to recoup losses of the various plant nutrients. Nitrogen and phosphorus can be added directly to the soil as chemical fertilizers for cotton, fruits, and many other cash crops. Replacement of nitrogen by the use of legumes is often more desirable in ordinary farm practice, since both nitrogen and humus are then added to the soil. Phosphorus cannot be added to the soil by the growing of legumes or any other crop, and it is not made available in appreciable quantities through the natural or geological erosion processes. Phosphorus must be replaced through the use of chemical fertilizers, once the original supply has been depleted. Farming practices in the United States in the past have not included the use of phosphate fertilizer in amounts equal to those being removed by crops and erosion. Consequently, soils have become partially depleted, and many of them have become significantly less productive because of a lack of phosphorus. A much more liberal use of phosphate than at present will be necessary if the reserve in the soil is to be brought up toward its former levels.

The known phosphate deposits in the United States are large, but they are in no sense inexhaustible. At the present rate of consumption, they might last several thousand years, but if phosphorus were to be applied to soils in amounts sufficient to offset losses and build up a reserve, the life of known deposits would be much shorter. The importance of phosphorus losses and the need for intelligent use and conservation of available supplies are, therefore, readily apparent.

Soils that have become partly or almost totally depleted of their plant nutrient supplies or have lost their structure are susceptible to further and accelerated losses through erosion. Doubtless most of the soils that have suffered erosion in the United States have passed through such a cycle. Actual removal of the soil itself is perhaps the most serious of soil losses. The conditions that have been slowly evolving in the soil throughout its development are all changed when accelerated erosion removes an appreciable part of the profile, whereas only one of the factors concerned in soil productivity is altered when structure is harmed through cultivation or nitrogen is lost in crops. Soil erosion, therefore, deserves special attention among soil losses, especially since many of the losses due to erosion are avoidable, and follow from misuse of the land or a previous depletion of the soil.

Erosion Reconnaissance Survey

Because of the seriousness of the Nation-wide erosion problem, an erosion reconnaissance survey was made in 1934 to determine the location and degree of erosion by wind and water. Neither time nor funds were available for the making of a detailed survey, but field workers covered each State, county by county, examined the soil at various stations, and mapped general erosion conditions. All of the land area of the United States, both agricultural and nonagricultural, was included in the survey. The data obtained are presented by geographic census divisions in table 3.

Table 3.—*Acreages affected and the degree of erosion by geographic regions*

Geographic division	Total area	Slight erosion (except locally)		Moderate erosion	
	Acres	*Acres*	*Percent*	*Acres*	*Percent*
New England	39,603,531	36,136,685	91.2	3,421,425	8.6
Middle Atlantic	63,932,395	38,170,914	59.7	24,203,123	37.9
East North Central	157,012,381	101,159,655	64.4	46,603,415	29.7
West North Central	326,785,527	169,553,374	51.9	110,547,744	33.8
South Atlantic	172,084,524	96,145,242	55.9	58,254,349	33.8
East South Central	114,966,646	20,867,469	18.1	59,633,056	51.9
West South Central	276,410,538	92,887,885	33.6	112,236,821	40.6
Mountain	548,871,903	63,757,642	11.6	265,880,663	48.4
Pacific	203,509,175	81,833,145	40.2	94,897,435	46.6
Total area	1,903,176,620	700,512,011	36.8	775,678,031	40.8

Geographic division	Severe erosion		Essentially destroyed for tillage		Mountains, mesas, and badlands	
	Acres	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*
New England	20,312	0.1	25,109	0.1	0	------
Middle Atlantic	1,426,037	2.2	132,321	.2	0	------
East North Central	5,901,951	3.8	3,347,360	2.1	0	------
West North Central	35,819,906	11.0	6,918,801	2.1	3,945,702	1.2
South Atlantic	12,205,520	7.1	5,479,413	3.2	0	------
East South Central	26,512,777	23.1	7,953,344	6.9	0	------
West South Central	25,489,808	9.2	25,216,849	9.1	20,579,175	7.5
Mountain	102,426,058	18.7	4,608,560	.8	112,198,980	20.5
Pacific	15,212,494	7.5	3,521,643	1.7	8,044,458	4.0
Total area	225,014,863	11.8	57,203,400	3.0	144,768,315	7.6

A number of separate and combined erosion classes mapped in the survey have been grouped under five major headings [6] for presentation in tabular form.

Information obtained by the survey indicates, in a general way, the areas damaged by erosion. It should be pointed out that it is not possible in a reconnaissance survey to make precise separations of different erosion classes. The reconnaissance data, therefore, have distinct limitations, but they furnish the best information available on the erosion conditions over the entire country. These figures are only intended to be preliminary, useful for planning broad regional measures of erosion control but not for making detailed erosion-control plans for separate farm units. The classes of erosion were defined as follows:

Slight erosion.—These areas have lost generally less than 25 percent of the original surface soil.[7] They include flat lands and swamps such as those of the lower Coastal Plains and the old glacial lake plains; most of the larger flood plains; gently undulating plains of the Midwest; smooth to gently undulating brush-covered plains of the arid West; forested lands that have been largely protected from erosion by vegetative cover; and slight wind-erosion areas having small amounts of soil removed and local accumulations of wind-blown material.

This class accounts for approximately 37 percent of the land area of the United States, or 700,500,000 acres. The cropland areas falling in this group can be largely protected from erosion by good crop rotations, supplemented by contour tillage operations where necessary. The pasture and wooded areas included in this group are likewise easily protected from erosion, owing to the soil and topographical conditions.

Moderate erosion.—This includes the following conditions occurring singly or in combination with each other or with slight erosion: 25 to 75 percent of the original surface soil lost and occasional or frequent gullies occurring either with slight or moderate sheet or wind erosion.

The acreage included in this class deserves attention for two reasons: (1) Approximately 41 percent of the land area of the United States falls in this group; and (2) the erosion problems can usually be solved today, but they may become difficult to control in a few years if allowed to go unchecked. The costs necessary to control erosion in this group at the present time are low as compared to the costs that will be necessary in the future to assure permanent utilization on these same acres, if they are allowed to go unprotected for a much longer period. Decidedly more rigid erosion-control practices should be recommended for this area than for those in the first group.

Severe erosion.—This includes the following conditions, occurring either singly or in combination with gullies or moderate sheet or wind erosion: Severe sheet erosion, where more than 75 percent of the original surface soil has been lost; and severe wind erosion, with large amounts of surface soil removed and local destructive accumulations.

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[6] Six classes are given on the map, p. 93, since it is advisable to show the location of wind-erosion areas.

[7] In mapping soil erosion it is necessary to estimate the proportion of the original surface soil that has been lost. This is done by comparing eroded soil profiles with undisturbed profiles of the same type in comparable situations. Surface soil is considered as roughly synonymous with the A horizon in most soils of the humid regions; in Podzols with a shallow A horizon it generally includes a part of the dark-brown B horizon. In Prairie soils and in most Pedocals it is the dark-colored surface horizon. Where soil profiles are not well developed or the horizons not easily distinguished, the plowed layer is considered the surface soil.

The area included in this group (225,015,000 acres) needs immediate attention to prevent erosion from devastating it. Approximately 12 percent of the entire land area of the United States is included in this class. To be sure, some parts are already submarginal as operated today, but it does not follow that, with proper land-use management and effective erosion-control practices, this area cannot be made safe for the future. In many instances cropland should be retired to grasses, pasture areas retired to woodland, and gullies stabilized. Dedication of this area to its proper land use is not sufficient to meet the problems; application of vegetative and mechanical control measures is needed to prevent further soil losses.

Essentially destroyed for tillage.—This includes combined severe sheet erosion and severe gullies; destructively large or frequent gullies; or extreme wind erosion.

Since presence of gullies or severe sheet or wind erosion does not prohibit some growth of certain grasses or trees, it is practically impossible to pronounce an area as entirely destroyed. In many instances, however, areas which once had good soil have been either entirely eroded or are in such condition that the land is practically worthless to the present generation. This classification accounts for approximately 57,203,000 acres, or 3 percent of the total land in the United States. Nearly half of this area is in the West South Central States.

Mesas, canyons, scablands, badlands, and rough mountain land.—Moderate to severe accelerated erosion caused by both water and wind occurs on some overgrazed mountainous lands. Approximately 7.6 percent of the land in the United States, or 144,768,000 acres, is in this class. The bulk of the acreage is in the western mountain States, where a division between geological erosion and man-made accelerated erosion is very difficult to establish. The area included in this group is not important from an erosion-control standpoint.

The map (fig. 1) shows six classes of erosion.[8] The first, where erosion is unimportant, except locally, is the same as the slight-erosion class, as defined. Two classes of slight erosion are shown on the map, one without and one with wind erosion. Severe erosion is similarly divided to show the occurrence of wind erosion. The class, essentially destroyed for tillage, as described, occurs in small disconnected areas that cannot be shown on a generalized map, but are included for the most part with severe-erosion classes.

Land Suitable for Cultivation

A Nation-wide appraisal has recently been made by Federal and State agricultural workers, to provide an estimate of land suitable for cultivation from the standpoint of erosion and soil losses. The objective was of a twofold nature—(1) to determine the amount of land in the United States, exclusive of possessions and territories, that is suitable for cultivation under prevailing price levels during the period 1921 to 1936 and is not subject to erosion injury under present methods of farming, and (2) to determine the amount of land that would be suitable for cultivation, assuming the same price levels, without

[8] Five classifications only are used in table 3, since wind-erosion and water-erosion areas were added together to allow comparisons for total erosion between geographical divisions.

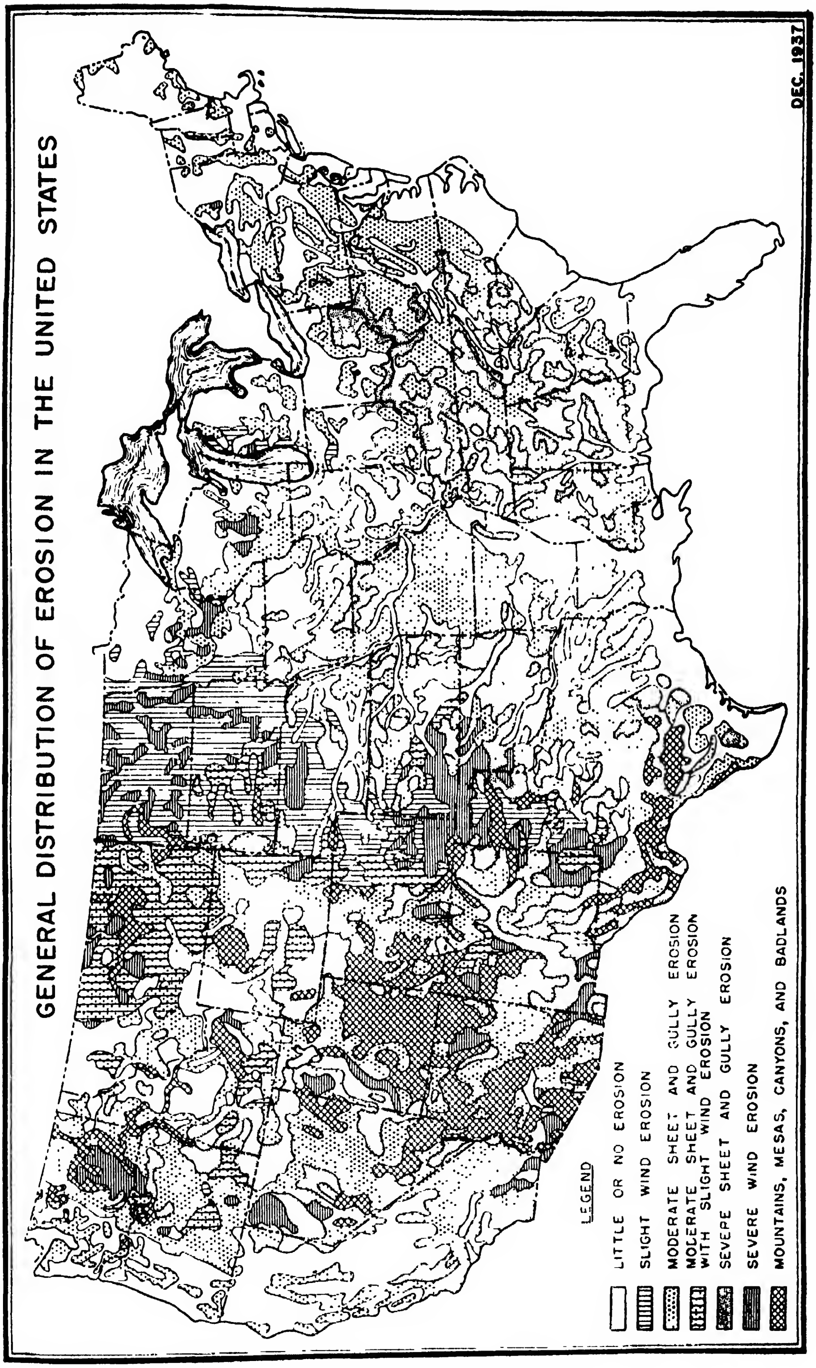

FIGURE 1.—General distribution of erosion in the United States.

erosion injury, if the best farming practices and erosion control methods were put into effect. In making the estimates, it was assumed that price levels for farm crops and livestock and costs of production would be about the same as those prevailing during the period 1921 to 1936.

Not only was the present cultivated area reviewed, but plowable pasture areas, land in brush or timber, and land in need of irrigation or drainage were also considered in arriving at final estimates. Basic figures for the appraisal were taken from the 1935 Census of Agriculture. The data were tabulated by counties and States, and are presented by geographic divisions in table 4.

The present cropland area of the United States, according to the 1935 Census of Agriculture, is 415,334,931 acres, including "cropland harvested," "crop failures," and "cropland idle or fallow." Of this area it is estimated that 60.9 percent is either subject to continued erosion under current practices or is of such poor quality as not to return a satisfactory income at the price levels assumed. Thus 39.1 percent or 160,948,703 acres can be expected to yield satisfactory returns and can be cultivated safely without serious erosion under present practices. This area would include those soil types that are not susceptible to appreciable erosion, the smooth portion of other soil types, and that soil whereon good rotations and other practices are providing erosion preventives. Of the 60.9 percent of the cropland area unsuited to cultivation under present practices and the price levels assumed, more than one-half (42.9 percent of the total cropland) is subject to erosion but could be used safely under good practices.[9]

Of those lands not now in cultivation, it is considered that 50,816,984 acres could safely be cultivated under present practices. These areas are for the most part plowable pastures in grass, or lands in brush and timber at the time the census was taken, with some smaller proportions of land that could be profitably and safely drained or irrigated. Including these areas, there is a total of 211,765,687 acres of land that can be safely cultivated under present practices and under price levels somewhat like those since 1920. This acreage is equivalent to 51.0 percent of the present cropland area.

In the event of widespread adoption of best soil-conservation and management practices, it is estimated that approximately 339,079,000 acres, or 82 percent of present cropland areas, would give adequate returns at the price levels assumed and could be safely operated without appreciable damage by erosion. On the other hand, it is estimated that by the use of the best conservation and management practices and under the price levels assumed, it would be possible to add a large area, approximately 108,386,770 acres, that is now in plowable pasture, brush or timber, or in need of drainage or irrigation. If this were done, the total area of land suitable for cultivation would be approximately 108 percent of the present cropland area, or 447,466,252 acres. This area is slightly more than double that suitable for cultivation under present practices and price levels assumed for the survey.

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[9] According to the estimates, 339,079,482 acres (table 4, column 11) of the land now in cultivation are suitable for cultivation under the conditions stated and with best practices, whereas only 160,948,703 acres (column 3) are suitable under price levels assumed and present practices. Thus 178,130,779 acres (or 42.9 percent of the present cultivated land) not now suitable could be considered suitable under good management practices and the price levels assumed.

Table 4.—*Estimates of land suitable for cultivation in continental United States*[1]

Geographic division	Land now in cultivation (1935 census)	Land suitable for cultivation under present practices: In cultivation		In plowable pasture	In brush or timber	In need of drainage	In need of irrigation	Total	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Acres	*Acres*	*Percent*[2]	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Percent*[2]
New England	4,303,401	1,736,646	40.4	103,143	....	....	....	1,839,789	42.7
Middle Atlantic	17,158,442	2,894,823	16.9	369,129	22,843	1,984	....	3,288,779	19.1
East North Central	64,758,999	38,009,771	57.8	6,568,996	3,127,172	678,496	....	48,384,435	74.7
West North Central	148,751,973	59,935,039	40.2	7,094,306	285,923	1,191,600	138,100	68,644,968	46.1
South Atlantic	35,099,820	9,943,499	28.3	1,015,910	4,003,802	1,873,609	600	16,837,420	47.9
East South Central	30,588,628	9,803,944	32.1	1,502,272	3,790,762	222,021	....	15,318,999	50.1
West South Central	65,222,331	21,828,643	33.5	3,347,079	8,238,937	1,994,323	790,706	36,199,688	55.5
Mountain	30,419,715	11,537,538	37.9	1,192,945	112,200	262,532	1,754,094	14,859,309	48.8
Pacific	19,031,622	5,258,800	27.6	417,900	271,600	205,000	236,000	6,392,300	33.6
Total	415,334,931	160,948,703	39.1	21,611,680	19,856,239	6,429,565	2,919,500	211,765,687	51.0

Geographic division	Land suitable for cultivation under best soil-conservation practices: In cultivation			In plowable pasture	In brush or timber	In need of drainage	In need of irrigation	Total		
(1)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	Acres	*Percent*[2]	*Percent*[3]	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Percent*[2]	*Percent*[3]
New England	3,579,142	83.2	206.1	336,127	....	....	....	3,915,269	91.0	225.4
Middle Atlantic	12,910,992	75.2	146.0	1,620,[illegible]20	73,276	1,984	....	14,607,172	85.1	504.6
East North Central	57,346,837	88.5	150.8	12,313,011	5,878,757	690,611	....	76,229,216	117.7	200.5
West North Central	128,410,635	86.3	214.2	20,248,118	599,393	1,213,900	349,800	150,821,846	101.4	251.6
South Atlantic	28,209,286	80.3	283.7	3,419,817	11,552,831	2,977,376	600	46,159,910	131.5	464.2
East South Central	19,727,870	64.5	201.2	5,138,369	7,203,114	222,021	....	32,291,374	105.6	329.4
West South Central	51,886,792	79.6	237.7	5,986,678	15,704,103	2,025,803	872,671	76,476,047	117.2	350.3
Mountain	21,658,006	71.2	187.7	2,497,136	181,670	292,426	2,538,658	27,167,896	89.3	235.5
Pacific	15,349,922	80.7	291.9	1,162,500	958,400	239,700	2,687,000	19,797,522	104.0	376.5
Total	339,079,482	81.6	208.5	52,722,676	42,151,544	7,663,821	5,848,729	447,466,252	107.7	278.0

[1] The estimates cover land suitable for cultivation under prevailing price levels during the period from 1921 to 1936 and not subject to erosion injury under present methods of farming and, second, the amount of land in the United States, assuming the same price levels, that would be suitable for cultivation without erosion injury if the best farming practices and erosion control methods were put into effect.
[2] Of column (2).
[3] Of column (3).

The appraisal further indicates that 178,130,779 acres of the present cropland area, or approximately 43 percent, is in need of good soil-conservation practices to assure prevention of serious damage from erosion. The scope of conservation is not limited to this acreage, however, since erosion and soil-fertility losses are also constantly in progress on overgrazed range land, pastures, and improperly managed woodland areas.

The appraisal as summarized indicates that there are 76,255,449 acres, or only 18 percent of the present cropland area, which cannot safely be cultivated if best soil-conservation practices are followed, and assuming price levels similar to those prevailing since 1920. If this proportion of the land needs to be retired, it still has other profitable uses, such as permanent pasture, woodland, wildlife habitats, etc. This submarginal area is divided among the 6,812,000 farms of the United States, and much of it may be used as a part of individual farm units for other uses than crop production when effectuating proper soil-conservation and management plans for the individual farms. Part of it, on the other hand, occurs in sufficiently large tracts so that it might well be owned and managed by public agencies to the best advantage of society.

In practically all instances, it is safe to assume that good soil conservation practices will increase production in the aggregate. Therefore, as more such practices are put into effect on the cropland areas, some provisions should be made to safeguard against an oversupply of farm produce with reference to existing outlets or demand. It is improbable that such needed regulation of crop production could best be brought about in any other way except by public administration, both locally and nationally. Such guidance should not only be de-designed to regulate total production of agricultural commodities, but also to give direction to different farm enterprises, so that proper utilization of the land will be effected.

EFFECT OF SOIL LOSSES ON CROP YIELDS

It is generally understood that without particular care in management soils become less productive under agriculture. Moreover, observations indicate that the soils over considerable areas of the country have deteriorated strikingly, owing primarily to injudicious management and the resulting erosion. It has been pointed out, however, that, when average yields are considered for the country as a whole, little or no decline is evident, and that for some crops the yields have been increasing. The problem then arises of reconciling the data regarding average crop yields with the prevailing ideas of soil deterioration.

Average yields per acre are not a safe or an accurate criterion of the productive capacity of all the land in a particular area, but only of the land actually in cultivation at the time the yield data were obtained. Average yields per acre of cultivated crops may be maintained or increased by decreasing the acreage and removing the less productive land from cultivation as it declines in productive capacity, or by shifting crops from less productive to more productive land. The maintenance or increase of yields through removal of poor land is illustrated by data for South Carolina (*117*). Cotton acreage in

that State decreased from a 1912–16 average of 2,728,000 acres to a 1932–36 average of 1,415,000 acres. It is evident that the poorer land was removed from cultivation, since for the same periods average yields per acre increased from 215 pounds to 251 pounds. Much land in the Piedmont section of the Southeast that once produced good crops of cotton is now so badly eroded as to be practically worthless for crop production. Crop-report records for that section, however, show that yields per acre have been fairly well maintained. The explanation lies largely in the fact that the badly eroded land has been retired as it declined in productive capacity. The retirement of land in the Piedmont has been somewhat in proportion to erosion. For example, in Fairfield County, where erosion is severe, cotton acreage has decreased 76 percent during the period 1900 to 1935, while the decrease in cotton acreage in Laurens County, where erosion is less severe, has been only 54 percent during the same period.

The shift of crops from less productive to more productive land is illustrated by data for Ohio. In that State, average yields per acre of corn for the decade 1920–29 were practically the same as those for the decade 1870–79. During this 60-year period, however, the corn acreage in five representative southeastern counties, consisting of relatively low-producing residual sandstone and shale soils, decreased 20 percent while the corn acreage in five representative northwestern counties, consisting of high-producing glacial limestone and glacial lake soils, increased 393 percent. Numerous similar examples might be given. It is evident, therefore, that average yield data for a farm, a State, or the country as a whole are not an accurate criterion of soil productivity. In order to evaluate such data, one must know what shifts, if any, have taken place in acreage.

Influence of Improved Cultural Techniques in Maintaining or Increasing Yields

The level of soil fertility is only one of the factors determining yields. There are many others, the influence of which may be difficult to evaluate; nevertheless for certain crops these other factors may represent striking yield increases.

The improvement of varieties and strains of crop plants has been one of the outstanding agronomic developments during the last half century. For individual States the average increase in certain cereal yields from this factor alone has been conservatively placed at from 2 to 5 bushels per acre. This undoubtedly accounts in no small measure for the sustained yields of these crops.

The adoption of crop rotations and cropping systems that include a larger use of legumes and a more limited use of grain or row crops is conducive to the maintenance or increase of yields. During the past 30 years such rotations have been generally adopted in many parts of the country, especially in the Northern States lying east of the Mississippi River.

The use of commercial fertilizer in the United States has increased from approximately 2,800,000 tons in 1899 to over 9,000,000 tons in 1929—the year before the sharp decline in agricultural prices. While the acreage of cropped land increased about 50 percent during this

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period, most of the increase was in newer parts of the country where small amounts of fertilizer are used. Most of the increase in the use of fertilizer, therefore, was for larger applications per acre rather than for application on a larger acreage at the same rate. For example, data for South Carolina, where a large percentage of the fertilizer is used on cotton, show that the cotton acreage in 1929 was slightly less than in 1890, but the use of fertilizer during this period increased from slightly less than 200,000 tons to 708,000 tons. In Ohio, where most of the fertilizer is used on wheat, oats, and corn, the combined acreage of these crops was practically the same in 1929 as in 1890, but the use of fertilizer increased during this period from less than 100,000 tons to 339,000 tons.

Another factor affecting crop yields is drainage. During the past 50 years, drainage has been responsible for marked improvement in the productive capacity of land already under the plow, as well as for bringing into production a considerable acreage of new land, thereby facilitating a shift in crops from less productive to more productive soils, either within the farm or from one part of the country to another.

Insects and plant diseases are other factors modifying crop yields. The best available information indicates that through improved control practices, insect damage is showing a trend downward that should result, were this the only limiting factor, in increased crop yields.

During the past decade marked improvement has been made in control of plant diseases. This has been brought about largely through the development of disease-resistant strains and through selection, certification, testing, and treatment of seed. While in certain areas and with certain crops, diseases are taking a heavier toll than formerly, on the whole it is believed that, other things being equal, the progress of disease control should have resulted in some improvement in the yields of general farm crops.

During the past 30 years, marked improvements have been made in machinery used in tilling the soil, and for the seeding, fertilizing, and harvesting of crops. This has facilitated better tillage, seeding, fertilizing, and harvesting methods as well as more timely operations. While improved machinery has resulted in more extensive operations and facilitated the bringing of additional land into production, especially in the Great Plains, its use, other things being equal, should also have resulted in increases in acre yields on areas already in cultivation previous to its advent.

During the past 50 years, agricultural science has been definitely concerned with the improvement of cultural techniques, and substantial progress has been made. As a result of these improvements, one would reasonably expect an increase in crop yields, provided the productive capacity of the soil remained the same. Since data for this period show that these increases have not come about, it is evident that the beneficial effects of these improved techniques have been counteracted, presumably by a decline in the productive capacity of the soil. In discussing this subject, Salter, Lewis, and Slipher (*335*) state:

Certainly, taken all together, all of these changes and improvements should have raised acre yields considerably—how much, it is difficult to say exactly, but we believe an increase of 40 to 60 percent would have been conservative. There can be but one explanation for the stubbornness with which acre yields have resisted the farmer's efforts to improve them: the natural productive capacity of the land has been deteriorating at a rate almost fast enough to offset all these improvements in soil and crop management. For every step ahead we have slipped back almost if not quite as far.

Evidence From Old Field Experiments

Experimental data indicate that the productive capacity of soil decreases with continued use. Quantitative data showing measured crop yields are available from long-established field experiments in a number of States. The data from such agricultural experiment stations as those of Pennsylvania, Ohio, Illinois, and Missouri have shown a decline in corn yields during a 30- to 40-year period of between 1 and 2 percent annually, for a standard crop rotation where all crops are removed and no manure or fertilizer is applied.

Another quantitative measure of soil deterioration is the amount of nitrogen in the soil. Data from a number of States indicate that during periods of 30 to 40 years, ordinary systems of cropping, even where erosion is not an important factor, have reduced the nitrogen content 25 to 40 percent, or about one-third. Under severe erosion and an excessive production of intertilled crops, nitrogen losses may greatly exceed these figures.

Effects of Erosion on Crop Yields

Calculations based on material furnished by authorities and subsequently reported by the National Resources Board (*435*) show that 99,300,000 tons of plant-food materials are lost annually from the surface soil of cropland in the United States, in addition to 37,200,000 tons removed annually from pastured areas. As shown in table 5, taken from the National Resources Board report, 22 percent of the nitrogen losses, 52 percent of the phosphorus losses, 58 percent of the potassium losses, 34 percent of the calcium losses, 49 percent of the magnesium losses, 10 percent of the sulphur losses, and 22 percent of the losses of organic matter are due to erosion.

Table 5.—*Plant nutrients annually lost from soils of the United States* [1]

Losses through—	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulphur	Organic matter
	1,000 tons	*1,000 tons*	*1,000 tons*	*1,000 tons*	*1,000 tons*	*1,000 tons*	*1,000 tons*
Crops (harvested areas)	4,600	700	3,200	1,000	500	500	92,000
Grazing (pastures)	3,000	500	3,700	1,000	500	400	60,000
Leaching (harvested areas)	4,000		6,600	26,600	6,000	7,400	80,000
Erosion (harvested areas)	2,500	900	15,000	13,000	6,000	800	50,000
Leaching (pastures)	1,000		1,700	7,000	1,600	1,900	20,000
Erosion (pastures)	1,000	400	6,000	5,000	2,200	300	20,000
Total	16,100	2,500	36,200	53,600	16,800	11,300	322,000

[1] Area considered: Harvested crops, 365 million acres; pasture and woodland grazing areas, 1,000 million acres.

Obviously, the amount of plant-food materials removed by erosion will depend upon the amount of erosion that takes place. Studies made in various States would indicate that erosion is one of the major

causes of soil depletion. Jenny (*185*) has stated: "There is one outstanding factor which lowers the fertility of many Missouri soils and that is soil erosion." Under conditions in North Carolina, Bartel [10] said:

> It is evident that a somewhat smaller proportion of nitrogen is lost through erosion than is removed by crops, but that 50 to 100 percent more phosphoric acid and about 50 to 60 times as much potash is lost by erosion as is removed by crops.

Duley and Miller (*95*) of Missouri report:

> Chemical analyses showed that the amounts of nitrogen, phosphorus, calcium and sulphur in the eroded material from corn or wheat may equal or exceed the amounts taken off in the crops.

That the removal of plant-food materials by erosion does have a detrimental effect on crop yields is common observation. This observation is supported by experimental data. As shown in table 6, data from experiments conducted at various erosion experiment stations show that yields on normal soil were 1½ to 33 times as large as on soils that had been artificially desurfaced.

In 1935 the Ohio Agricultural Experiment Station made erosion studies on their continuous corn and oats plots, which had been under observation since 1894. As shown in table 7, it was found that 5.5 to 11.1 inches of soil had been eroded from these various plots. The organic matter ranged from 35 to 97 percent of that of 1894. Yields had likewise declined. What percentage of this decline in yields or in organic matter was due to erosion and what percentage was due to other causes is impossible to determine with the information at hand. It is evident, however, that the plow soil on these plots in 1935 was far different from that of 41 years previous, and it appears reasonable to believe that much of the organic matter and plant-food materials were lost through physical movement of soil from these plots.

Results similar to those obtained at experiment stations have been obtained from practical field tests. In the spring of 1934, on Houston soils near Temple, Tex., uniform pedigreed Qualla cottonseed was planted at approximately the same date on a number of areas affected in different degrees by erosion. All fields were cultivated and treated under observation and in as nearly the same manner as possible. The results of these tests (table 8) show that the reduction in yield, which was apparently due to erosion, ranged from 61 to 98 percent.

The results of a field test, conducted in quadruplicate on Cecil sandy loam soils that had lost different amounts of soil by erosion under field cropping conditions, show (table 9) that yields on subsoil (B horizon) were only 14.6 percent of those on surface soil (A horizon), while the substratum (C horizon) produced only 4.6 percent as much as surface soil. The indication is that essentially the same results are obtained where erosion took place under field cropping conditions as are obtained where the soil is artificially desurfaced.

Uhland and Wooley (*422*) have stated:

> It is probably safe to say that the fertility of the average Missouri upland soil has already declined at least one-fifth by soil washing, while on the more rolling lands the decrease has been much greater.

[10] BARTEL, F. O. PROGRESS REPORT OF NORTH CAROLINA EXPERIMENT STATION, 1928. [Mimeographed.]

Table 6.—*Annual yields from normal soils and desurfaced soils of similarly treated plots of standard size at the Soil Conservation Service experiment stations* [1]

Soil	Location	Slope (percent)	Soil amendments	Period	Crop	Annual yield from— Normal soil	Annual yield from— Desurfaced soil
Houston black clay	Temple, Tex.	4	None	1931 and 1934	Corn	26.8 bushels	2.9 bushels.
				1932 and 1935	Oats	60.6 bushels	22.5 bushels.
				1933 and 1936	Cotton, lint	288 pounds	102 pounds.
Marshall silt loam	Clarinda, Iowa	9	do	1932–35	Corn	30.5 bushels	6.5 bushels.
Clinton silt loam	La Crosse, Wis.	16	do	1933–34	do	49.3 bushels	21.2 bushels.
Muskingum silt loam	Zanesville, Ohio	12	do	1933, 1935, and 1936	Corn, grain	35.3 bushels	1.1 bushels.
					Corn, stover	4,258 pounds	510 pounds.
Palouse silt loam	Pullman, Wash.	30	do	1932–35	Winter wheat	23.9 bushels	7.2 bushels.
Colby silt loam	Hays, Kans.	5	do	1930 and 1935	do	12.5 bushels	5.3 bushels.
Kirvin fine sandy loam	Tyler, Tex.	8¾	do	1931–34	Cotton, seed	365 pounds	50 pounds.
			400 pounds 4-8-4	1936	do	370 pounds	100 pounds.
Nacogdoches fine sandy loam	do	10	None	1931–34	do	308 pounds	13 pounds.
			400 pounds 4-8-4	1936	do	450 pounds	130 pounds.
Cecil sandy clay loam	Statesville, N. C.	10	None	1932–34	do	950 pounds	290 pounds.
Vernon fine sandy loam	Guthrie, Okla.	7.7	do	1929–36	Cotton, lint	159 pounds	96 pounds.
			Virgin soil 1929	1930–35	Cotton, seed	495 pounds	313 pounds.

[1] Data compiled by G. W. Musgrave, in charge of Soil and Water Conservation Experiment Stations, U. S. Department of Agriculture.

Table 7.—*Soil loss, organic matter, and yields on continuous corn and oats plots, Ohio Agricultural Experiment Station, Wooster, Ohio, 1894–1935*

Crop	Plot	Treatment	Soil loss	Organic matter (1894=100)	Average yield per acre 1894–98	Average yield per acre 1931–35
			Inches	*Percent*	*Bushels*	*Bushels*
Continuous corn	1–4 7–10	None	10.3	37	26.3	6.5
	8	Complete fertilizer [1]	11.1	35	44.4	28.9
	6	Manure, 5 tons [2]	9.5	53	43.1	30.0
Continuous oats	1–4 7–10	None	6.7	64	28.2	14.2
	8	Complete fertilizer	5.5	91	48.8	38.8
	6	Manure, 5 tons [2]	5.6	97	34.8	34.6

[1] Equivalent to 500 pounds 10–5–10.
[2] Per acre.

Table 8.—*Yields from areas only slightly eroded and from areas severely eroded, on Houston soil, with approximately equal rainfall, near Temple, Tex., 1934* [1]

Field	Size of field	Condition of erosion	Yield per acre of seed cotton	Field	Size of field	Condition of erosion	Yield per acre of seed cotton
	Acres		*Pounds*		*Acres*		*Pounds*
1	10	Slight	604	7	4	75 percent of topsoil washed off	241
2	6.4	do	771	3	13.5	All topsoil washed off	46
5	8	60 percent of topsoil washed off	12	6	0.5	do	262
4	16	75 percent of topsoil washed off	25				

[1] From annual report, Elm Creek Erosion Control Project, Temple, Tex., 1935

Table 9.—*Difference in yields from surface soil, subsoil, and substratum material of Cecil sandy loam, 1936, Spartanburg, S. C.* [1]

Degree of erosion	Average yield per acre of seed cotton	Reduction in yield
	Pounds	*Percent*
Surface soil (A horizon)	1,609	------
Subsoil (B horizon)	234	85.4
Substratum (C horizon)	74	95.4

[1] Test conducted by T. C. Peele, Soil Conservation Service.

It is extremely difficult to restore the fertility of eroded soil, even though liberal amounts of fertilizer are added. This is shown (table 10) by experiments conducted at Tyler, Tex., and Statesville, N. C. At the Tyler station, desurfaced plots treated with an annual application of 400 pounds per acre of 4–12–4 fertilizer and a green-manure crop plowed under annually produced only 61 percent as much cotton as normal plots without either fertilizer or green manure. At the Statesville station, desurfaced plots treated annually with 600 pounds per acre of 5–10–3 fertilizer and a green-manure crop plowed under produced only 77 percent as much cotton as normal plots with no

fertilizer or green manure. This would indicate that fairly liberal applications of fertilizer together with green manure cannot entirely compensate for loss of topsoil.

It is evident, therefore, that erosion is a major factor in crop yields. Through the removal of topsoil, available plant-food materials are removed. Probably one of the most detrimental effects of erosion is the removal of organic matter, with the resultant decrease in bacterial action and in water-holding capacity.

On the whole, the data warrant the conclusion that the original fertility of the majority of the cultivated soils of the United States has declined materially during the period of cultivation, and that erosion has been one of the major factors in this decline. In spite of the constant retirement of poor land, the shift to more fertile soils, and the adoption of improved techniques, average crop yields have not increased. The realization of this situation should focus increased attention on the difficult problem of soil conservation.

Table 10.—*Yields of seed cotton on fertilized and unfertilized plots of normal soil and desurfaced soil, at Tyler, Tex., and Statesville, N. C., Soil and Water Conservation Experiment Stations*

Station	Soil	Period	Crop	Average yield per acre, normal soil		Average yield per acre, desurfaced soil	
				Unfertilized	Fertilized [1]	Unfertilized	Fertilized [2]
				Pounds	*Pounds*	*Pounds*	*Pounds*
Tyler	Kirvin fine sandy loam.	1931-34	Seed cotton	360	580	50	225
Statesville	Cecil sandy clay loam.	1932-34 and 1936	do	934	--------	225	727

[1] Fertilizer treatment, normal soil plots: Tyler, 400 pounds of 4-12-4 per acre per year; no green manure.
[2] Fertilizer treatment, desurfaced plots: Tyler, 400 pounds of 4-12-4 per acre per year and oats plowed under as green manure. Statesville, 600 pounds of 5-10-3 per acre per year and cowpeas plowed under as green manure.

THE EFFECT OF SOIL EROSION ON FLOODS, NAVIGATION, WATER-POWER DEVELOPMENT, AND WATER CONSERVATION

Discussion of the effect of soil erosion on floods is fraught with the hazard of arriving at premature conclusions. That there is a definite relationship between the two problems is widely accepted, for the premise of the relationship is plain—floods are concentrations of water in excess of stream-channel capacity, and since eroding land sheds water in greater volume and with greater velocity than noneroding land, erosion adds to the danger and damage of floods. Moreover, erosion results in the deposition of abnormal quantities of silt in the smaller stream channels, further increasing the possibility of floods by decreasing the water-carrying capacity of the channels.

Precisely to what degree erosion affects floods, however, has not yet been determined. Correlative investigations undertaken so far have been limited, although surveys and studies of the interlocking aspects of the two problems are now being made as rapidly as possible by the

Department of Agriculture. In all probability, it will never be possible to reduce the relationship to terms of a specific formula. Soil, slope, climate, land cover, and land use, which are the prime factors of erosion, vary so greatly from watershed to watershed and from drainage basin to drainage basin that any all-inclusive formula would probably be ineffective. On any specific small watershed, however, there is every possibility that the relationship of soil erosion to floods may be accurately determined.

The measurements and observations of water run-off and soil removal from areas in varying conditions of erodibility are evidence of the importance of erosion as a force contributing to excessive concentrations of water.

During December 1931 and January 1932, when 27 inches of rain fell in the watershed of the Yazoo River in Mississippi and gave rise to a disastrous flood, 62 percent of the rainfall immediately ran off plots in cultivated fields and carried soil with it at the rate of 34 tons per acre. The run-off from plots on barren, abandoned fields was 54 percent of the total rainfall. During periods of most intense rain, surface run-off from these areas increased to 75 to 95 percent of the precipitation.

On the other hand, less than 0.5 percent of the 27 inches of rain falling on undisturbed oak forest ran off the surface of experimental plots. Soil was removed at a rate of only 75 pounds per acre.

Records of the continuous flow of streams from eight small watersheds in the Appalachian region, near Asheville, N. C., for periods of from 1 to 2½ years, indicate the stabilizing influence of forest and other vegetative cover on water run-off. Between July 1, 1933, and October 30, 1936, the average maximum flood flow from forested watersheds was 6 cubic feet per second per square mile. From abandoned agricultural land the flow was 403 cubic feet per second per square mile, and from gullied pasture land 785 cubic feet per second per square mile. In no case did the storm run-off from forested watersheds assume critical flood conditions, whereas from the nonforested watersheds there were numerous instances in which the maximum flow assumed serious flood proportions.

The relationship of ground-cover condition to peak stream flow is further demonstrated by studies in Cooper Basin, Tenn., where a hardwood forest and other plant cover have been completely destroyed by smelter fumes. From this denuded watershed, run-off has attained a maximum flow of 1,263 cubic feet per second per square mile. From a nearby incomplete broomsedge cover and from an adjoining forested watershed, there was a maximum flow of 832 and 30 cubic feet per second per square mile, respectively.

On January 1, 1934, a disastrous flood swept out of Verdugo and Haines Canyons in Los Angeles County, Calif., after a 12.5-inch rain fell in 2½ days over a 50-mile belt of foothills and mountains. The watersheds in which this destructive local flood originated, an area of about 4,000 acres, had been partially burned over only a few weeks earlier. The maximum flood discharge from the two drainage basins reached 1,000 cubic feet per second per square mile. The erosion debris transported by the run-off amounted to 50,000 to 67,000 cubic yards per square mile. Neighboring watersheds subject to the

same rainfall but with their forest cover intact, yielded clear water but produced no floods or unusual damage.

Observations in the Santa Clara Valley of California show that run-off may increase from 12 to 20 times when the slopes have been stripped of vegetation by fire.

At Tyler, Tex., in a district of gentle slopes with an annual rainfall of 40 inches, clearing and cultivating the land increased the run-off 28 times and the soil losses 239 times (4-year average, 1931–34).

At Bethany, Mo., fallow land typical of the southern portion of the Corn Belt lost 235 times as much soil and 3 times as much water in run-off as similar land covered with grass (5-year average, 1931–35).

Land under native grass in the Appalachian hill section near Zanesville, Ohio, lost only 4.5 percent of the total rainfall as surface run-off. A nearby plot left fallow lost 42.5 percent, while another plot planted continuously to corn lost 35.2 percent of the rainfall as run-off (2-year average, 1934–35).

Data obtained at the Guthrie, Okla., Erosion Experiment Station show that the water run-off from land cultivated continuously to cotton was 11 times greater and the soil loss 760 times greater than from the same kind of land covered with ungrazed Bermuda grass (6-year average, 1930–35).

It is not to be inferred, however, that denudation of land and subsequent erosion are solely responsible for floods. Although measurements and observations on small streams indicate that diminution of vegetal cover and subsequent erosion of the land increase the tendency of such streams to flood, other factors may readily be of equal or greater importance.

For example, prolonged, intense rains, falling on a limited area bordering a stream, would probably result in a flood on that stream regardless of the extent and degree of erosion on nearby land. Frozen ground that forbids any appreciable water infiltration into the soil is another flood-inducing factor, while a combination of melting snow and concentrated rainfall, in conjunction with frozen ground, may produce a climatic and hydrologic alignment that would make a flood inevitable.

The fact that eroded land is not the sole cause of floods, however, does not refute evidence that such land often contributes to the accumulation and concentration of potential flood waters. Thousands of observations clearly prove that gullies, impervious subsoil, and unprotected surface soil speed the transit of precipitation to streams and almost invariably shed more water than land undamaged by erosion.

It is logical reasoning, therefore, that the difference in annual run-off between an acre of noneroded land and an acre of land eroded to the average degree for the United States, multiplied by the number of eroded acres in the country, gives in a general way the total increase in annual run-off attributable to erosion. Expressed in flood terms, the increase in annual run-off following erosion is an additional volume of potential floodwater—water that would otherwise be held on the land.

Logical also is the reasoning that every increase in the extent and degree of erosion paves the way for still further additions to the total annual volume of potential floodwaters.

Corroboration of this premise may be found in the alluvial deposits along numerous streams in various sections of the country. Geolo-

gists have determined that much of the material forming these alluvial plains was deposited by floodwaters through a process of sedimentation which probably began millions of years ago. Overlying the alluvial soil material laid down by floods of preagricultural times is a different kind of alluvium that has been spread out by floods occurring since the continent was opened up for agricultural use.

There is a marked difference between the old material and the new. The preagricultural deposits in many places have a cover of comparatively fine texture and uniform composition which indicate that they were probably developed under conditions of relatively low velocity overflow. The general character of many of the later sediments, however, shows that they were spread over the flood plains by waters much more violent and more heavily laden with erosional debris. The newer deposits are not only frequently coarser in texture, but their irregular textural composition and color characteristics show greater variation in the conditions of deposition. In fact, the line of separation between the two types of alluvium—the preagricultural and agricultural—is sometimes so distinct that it is possible to photograph it without difficulty.

In some instances, the depth of the new material is greater than the entire depth of the old deposits lying underneath, even though the former was accumulated in many places within 25 to 75 years, whereas the buried material probably was deposited over a period of thousands of years.

It is often said that erosion goes on anyway, whether or not the land is cultivated. But the relatively sudden increase in thickness, as well as the variations in color and texture of the new material as compared with the old, show the effects of greater velocity and volume of run-off following land settlement and subsequent erosion. In turn, this evidence may rightfully be interpreted as indicating the importance of increased run-off in adding to flood hazards.

Rising river beds of the Rio Grande in central New Mexico and the Arkansas in western Kansas are also indicative of the contribution of erosion to the flood problem. The bed of the Rio Grande has risen 5 feet in 9 years and that of the Arkansas 5 feet during the past 45 years. Following the disastrous 1913 flood, channel improvements costing $3,500,000 were made to allow for a flood flow of the Scioto River at Columbus, Ohio, approximating that experienced in 1913. Silting, however, has reduced the capacity of the improved channel to such an extent that it may not now carry safely more than half the discharge of the 1913 flood.

Channels of smaller streams throughout eroded sections of the country are being subjected to similarly rapid sedimentation. The result is a reduction in the water-carrying capacity of the channels and a consequent diminished ability to cope with floods.

While stream-channel sedimentation is a decidedly complicating factor in the flood problem, it has other damaging effects. It has impaired the navigability of numerous streams and hampered transportation generally. For example, ships cannot now approach within many miles of formerly accessible points along the Coldwater River in Mississippi because the channel is choked with silt and sand.

For the past 7 years engineers have spent thousands of dollars annually to maintain a channel 6 feet deep for navigation through Lake St. Croix in Wisconsin. This lake, which has an average depth of over 30 feet and an average width of 3,000 feet, is only 200 feet wide where deltas have been built into it by the Willow and Kinnickinick Rivers. The erosional debris washed from the watersheds of the two rivers tends to fill the 6-foot navigation channel, thereby necessitating periodic dredging operations to maintain even this depth of water.

Similar examples of sedimentation damage to stream-channel navigability in other sections of the country are known, but so far the recorded data on the cost of maintaining navigability, and actual reductions in navigability, have not been compiled and interpreted in terms of soil erosion. Basic information exists, but research investigations are necessary to determine what proportion of the damage is the result of erosion and what proportion is the result of other factors.

Observations and studies to date indicate that sedimentary damage directly attributable to erosion is much more apparent, and probably more prevalent, in small streams and tributaries than in the trunk streams. Whereas any considerable deposition of sediment in smaller stream channels can often be traced to specific areas of erosion in the watershed, the ultimate source of sediment in the larger river channels is not so readily identified.

Whatever the immediate source of sediment in the trunk streams may be, it is reasonable to assume that a considerable part of the material was at some time washed from eroding lands. The relationship of soil erosion to the accelerated sedimentation of the smaller streams has already been established. Some of these small channels have been filled completely as a direct result of soil erosion. In brief, any thorough summation of the factors involved in the maintenance of navigability on the streams of the country must give prominent consideration to soil erosion. Certainly the existing evidence indicates that if reasonable precautions were taken to control soil erosion, the cost of maintaining navigability would be reduced.

As a general rule, the silting of reservoirs may also be traced directly to soil erosion. The Soil Conservation Service is studying this relationship and to date has completed 55 detailed reservoir surveys. Thirty-four reservoirs have been surveyed by other agencies. In addition, the Service has inspected 500 other reservoirs and for a majority of these has made sediment reconnaissance measurements.

Most reservoirs of the United States have a multiple use, even though they may have been created for a single purpose. For example, many reservoirs built for municipal water supply or hydroelectric power purposes also provide some degree of flood control. Other reservoirs with irrigation as their primary objective also provide power and flood control. In recent years, plans for new reservoirs have generally recognized and specifically provided for all possible functions. Actually, the single-purpose reservoir is a comparative rarity.

Whatever the function or functions of a reservoir may be, however, they have little if any effect on its susceptibility to silting. Studies

show that silt is piling up at an alarming rate in many reservoirs of all types.

Four channel reservoirs along the New River in southwestern Virginia, built to provide hydroelectric power, have been subjected to high rates of silting. Fields Reservoir, the uppermost, has lost 41 percent of its capacity in the 6 years since it was built. Washington Mills Reservoir, 43 miles downstream, has lost 83 percent of its capacity in 33½ years. Byllesby Reservoir, 9 miles below Washington Mills, silted 60 percent in 23 years, and Buck Reservoir, 3 miles below Byllesby, silted 23 percent in 23 years.

Lake Waco, a $2,000,000 reservoir, was created in 1930 on the Brazos River at Waco, Tex., to provide municipal water, but it also has some flood-control effect. Originally, the reservoir stored 39,378 acre-feet of water, but a survey in 1936 showed a storage loss of 19.78 percent, or an average loss of 3.34 percent a year. If the average rate of silting for this 6-year period continues, the reservoir capacity will be exhausted in another 24 years.

Lake Taneycomo on White River in Missouri is one of the largest channel-type reservoirs in the country. It provides both hydroelectric power and some measure of protection against floods, but in a little less than 22½ years silt has reduced the original storage capacity of 43,980 acre-feet of water by more than 46 percent, an average annual loss of more than 2 percent.

Lake Decatur on the Sangamon River in Illinois is the second largest reservoir in that State. It serves as the municipal water supply for Decatur, Ill., and also aids in flood control. The original storage capacity of 19,738 acre-feet of water has been reduced 14.23 percent in 14.2 years. Of the smaller storage reservoirs in Illinois, Lake Bracken at Galesburg has filled nearly 8 percent in 13 years, West Frankfort Reservoir 8 percent in 10 years, and Lake Calhoun at Galva, a recreational center, 52 percent in 12 years.

Elephant Butte Reservoir was built on the Rio Grande in New Mexico in 1915 to provide water for irrigation, but it also prevents all floods down to El Paso, except those of strictly local origin. A survey in 1935 showed that 367,600 acre-feet of silt had accumulated in the reservoir during the 20-year interval, reducing the storage capacity by approximately 14 percent.

Other reservoirs in other sections of the country are losing storage capacity at similarly varying rates. Only those in entirely forested headwater areas are without some silting, and the reservoirs in which sufficient excess capacity has been provided for silt storage are the exception rather than the rule.

The toll of silt on the effectiveness of reservoirs for flood control has not yet been fully imposed, but all existing evidence points to its inevitability. The cost of hydraulic dredging and mechanical removal of silt from reservoirs is prohibitive, except for those special-purpose reservoirs where no alternative is possible. Sooner or later, if the present rate of soil erosion and silting continues, most reservoirs will lose all utility. Present studies indicate that 38 percent of the existing reservoirs of the United States will have a useful life of only 1 to 50 years, 24 percent a life of 50 to 100 years, 21 percent a life of 100 to 200 years, and only 17 percent a life of more than 200 years.

Reservoirs with a primary function of flood control are few and relatively new, the oldest of appreciable importance having been built in 1915. Although these reservoirs are catching silt in the same manner as those with only a secondary flood-control value, enormous quantities of silt can be received by their necessarily vast storage basins before it begins to impair the effectiveness of the reservoir.

In contrast, many water-power dams and reservoirs have already lost all effectiveness or suffered a considerable reduction in effectiveness as a result of silting. Dams of this type were among the first built in the United States. Usually they were small, and located in relatively small streams. Because they were small, and because they were subjected to the silting process almost from the moment of their construction, these early reservoirs have become outstanding examples of destruction by silt.

Throughout the Piedmont section of the Southeast are numerous silt-filled reservoirs that once provided a steady flow of water for power development. Generally the adjoining power houses and mills have been abandoned. While it is true that obsolescence of machinery played an important part in the abandonment of many of these enterprises, the steady rise of silt was undoubtedly a major factor.

In other sections of the country the usefulness of numerous dams and reservoirs that were built for irrigation and water-power development during the latter part of the nineteenth century and up to 1910 has been reduced by silting, but not at the same rate as the earlier and smaller types. The construction of upstream subsidiary dams and sediment-detention basins as a protection against silting has prolonged the life of some of these reservoirs, particularly in the Western States.

Major hydroelectric power developments built since 1910 have not yet lost productive capacity from silting, and because of their size and recency will probably be able to maintain effectiveness for many years before silt becomes an acute problem. That it will eventually become such a problem unless soil erosion is controlled in the contributing watersheds is a foregone conclusion.

It has been estimated that approximately 3 billion tons of soil are washed annually from the overgrazed pastures and cultivated or barren fields of the country. This soil is poured into streams, harbors, reservoirs, lakes, and oceans, or deposited on bottom lands and flood plains. Probably two-thirds of it becomes, at least temporarily, sedimentary deposits in stream channels, harbors, and reservoirs, or is stranded elsewhere on its interrupted journey to the sea.

Further, recent sedimentation studies clearly indicate that it will be virtually impossible to maintain permanently the effectiveness of water-storage and flood-control developments in many valleys until erosion of the soil has been controlled along the headwaters of contributory streams.

An apparent corollary of increased water run-off and surface-soil removal by erosion is decreased ground-water supply. To date, however, investigation into this aspect of the erosion problem has been too limited to substantiate such a deduction; the best available evidence is no more than inferential. Observations in isolated areas indicate that control of erosion tends to restore the flow of springs and raise the height of water in wells. This does not necessarily mean,

however, that erosion reduces spring flow and lowers the level of water in wells. The sources of underground water are numerous, and the relative importance of any one source to the total volume of underground water supply in a specific area can be determined only by a comprehensive investigation of all possible sources. By the same token, variations in water tables may or may not be attributable to changes in surface conditions such as soil erosion causes. It is pertinent, however, to point out that despite the general absence of data on causes of fluctuation in ground-water tables, it is quite possible that erosion is at least as important as any other single cause.

ONE REASON *for misuse of the soil is the ignorance of individuals or their unfitness for farming. But even a wise and able farmer is not always in a position to adopt soil-conserving practices that in the long run are for his own good and that of his community and his country. To what extent do our traditional land policies stand in the way of good soil use? Is land speculation a factor? Are there dangers in our methods of giving emergency credit, adjustment benefits, and other aids? This article discusses such questions and closes with a brief survey of the experience of some countries in Europe.*

The Causes: Traditional Attitudes and Institutions

By L. C. Gray, John B. Bennett, Erich Kraemer, *and* W. N. Sparhawk [1]

AMERICA'S TRADITIONAL LAND POLICY [2]

THE policies which have governed the management and disposition of land in the United States have given little encouragement to the conservation and sound utilization of natural resources. On the contrary, they have frequently opened the door to wasteful exploitation and have hindered the development of a realistic program for constructive land use.

Until recent years, the United States had no comprehensive land policy, if by that is meant a comprehensive and well-thought-out plan for the most beneficial use of land resources. We have, by and large, believed it wise to turn over all lands to private owners as rapidly as possible, in the firm conviction that once in private hands land would automatically be utilized for its best purpose. Consequently, until recent years, American land policy has been chiefly a policy for the distribution of the public domain.

Two important influences in early American life are in large measure responsible for the failure of the American people to develop a constructive attitude toward land. The first of these was the great abundance of natural resources that the colonists and later settlers

[1] The sections headed America's Traditional Land Policy, The System of Inheritance, and Land Values, Land Speculation, and Land Settlement are by L. C. Gray, Assistant Chief, Division of Land Conservation and Land Utilization, Bureau of Agricultural Economics. The section headed Public Aids as a Cause of Land Misuse is by John B. Bennett, Senior Agricultural Economist, in charge, Land Policy Section, Division of Land Economics, Bureau of Agricultural Economics. In the section European Views on Land Tenure, European Agricultural Land-Tenure Laws is by Erich Kraemer, Associate Agricultural Economist, Farm Security Administration, and Property Rights and Forest Land Management in Europe is by W. N. Sparhawk, Senior Forest Economist, Division of Forest Economics, Forest Service.

[2] Acknowledgment is made to John Dreier of the Bureau of Agricultural Economics for assistance in preparing this section.

found. There was neither thought nor need for conservation; the pioneer had to destroy the wilderness that surrounded him before he could establish his farm and support his family. Habits of thought toward land and its resources were formed in an environment where the consequences of waste and destruction could always be avoided by moving to fresh lands.

The second of these influences was the general development in the American world of a strongly individualistic way of life, which in the economic realm was expressed by the philosophy of laissez faire. Under these influences, principles of land tenure and peasant agriculture that still prevailed in Europe gradually lost their validity in the American scene. Colonial companies and proprietors were unable to enforce such restrictions upon land tenure and land use as they attempted to impose. By the time of the Revolutionary War or shortly thereafter, force of circumstance associated with new economic and political philosophies had converted the restrictive elements in the system of land tenure that had been introduced at one time or another in most of the colonies into an American system based upon title in fee simple absolute.

Possibly the strongest feature of the American attitude toward land was the belief that every man enjoyed a right to the unrestricted ownership of a piece of the earth. Those who favored this concept, particularly the people of the frontier communities, argued with Thomas Jefferson that the distribution of public lands directly to settler families was one of the most desirable methods of building up a strong democratic citizenry. Opposed to them were the more conservative eastern groups who viewed the public lands primarily as a source of revenue to be disposed of in such a manner as to yield the largest possible income to the Government. Arrayed against the pioneer settler was the large-scale speculator, who saw the opportunity of making large profits in the process of buying up public land at the frontier at low prices and reselling it later to actual settlers. From the time of the establishment of the public domain in 1787 to the passage of the Homestead Act in 1862, American land policy was characterized by the struggle between these two interests. Step by step the settler interest won its way, first securing lower prices for land, then winning recognition of the settler's preemption rights, and finally obtaining the passage of the Homestead Act, which permitted the head of a family to obtain 160 acres of land practically free of cost by taking up residence on it for 5 years.

Under this simple and liberal land policy, the public domain of the United States, which totaled some 1,400,000,000 acres of land, was settled in a remarkably short time. Only a century elapsed between the formation of the Federal Government and the announcement by the Director of the Census that the frontier no longer existed. In 1935, when the homestead policy was brought to an end, the tremendous unappropriated public domain had shrunk to 165,000,000 acres of land mostly arid and unsuited to settlement. Simple though this policy was, however, it soon became apparent that even under the Homestead Act's provisions, the objective of developing a nation of land-owning farmers was not being realized. Corporations and large-scale speculators continued to acquire large acreages, both through

direct purchase from the Government, which was permitted until 1891, and through the false representations of agents posing as homesteaders. The system of commutation, whereby a settler could acquire the homestead 6 months after filing his claim by paying the mininum price, made abuse of the homestead policy particularly easy. In 1880, when the Census Bureau first counted the number of farm tenants as distinguished from farm owners, it was discovered that one-quarter of the Nation's farmers were renting their farms.

The lack of any well-thought-out land policy is illustrated by the treatment of timberlands on the public domain. Throughout the colonial period and for more than a century after the birth of the Republic there was no distinctive policy of significance to prevent the wastage of timber resources. In 1878 the Timber and Stone Act authorized individuals to acquire 160 acres of land chiefly valuable for timber or stone at a minimum of $2.50 per acre. This was nothing more than a legal procedure for turning timber over to private owners and embraced no policy of conservation. Like the various features of the homestead policy, the Timber and Stone Act was abused on a large scale. Corporations and other large landowners acquired thousands of acres of the best timberlands through misrepresentation by dummy entrymen, and proceeded to devastate vast areas of the Nation's finest forests. Finally, the policy of reserving timberlands, inaugurated on a large scale by President Theodore Roosevelt, helped to conserve the supply not yet transferred to private ownership. On privately owned timberlands, however, the practice of wholesale wastefulness still predominates.

Outside of making land easily available in convenient units, our land policy has been characterized by an almost complete lack of any positive attempt to give rational direction to land settlement. There have been few safeguards against settlement on unsuitable lands. Attempts at regulating size of holdings have been limited to measures to restrict the amount of land initially acquired. Even these requirements have been essentially unrealistic in relation to the varied physical and economic conditions of different parts of the country. Moreover, virtually no effective means were adopted to prevent undue concentration of ownership or uneconomic subdivision of holdings. While our policy freely reflected the ideal of ownership, no restrictions on disposition were introduced capable of preventing a high percentage of tenancy and extensive absentee ownership.

The application of the homestead policy to the Great Plains illustrates the unrealistic character of our land policy in its land-settlement aspects. Provisions of the act were drawn up to fit conditions of the moist Mississippi Valley, where 160 acres usually constituted an ample unit for a family farm. Settlement rapidly crossed the 100th meridian and entered the arid sections of the western plains, where 160 acres constituted a highly inadequate unit of operation. Yet it was not until 1904 that the Kinkaid Act permitted homesteads of 640 acres in the Nebraska sand hills, and not for 5 years more was a 320-acre homestead established for any large area. Moreover, these enlarged homesteads, including the stock-raising homestead of 1916, proved to be little more than a gesture in the right direction. No effective provision was made to determine the true character of the land or to

protect settlers in the investment of their life's savings and their hopes. Widespread farm abandonment, heavy costs for relief and emergency loans, the need for a repurchase program to take back certain of these lands into public ownership, and the devastation of millions of acres through wind erosion are among the heavy costs that the Nation now has to bear as a result of the unrealistic land policy that governed the settlement of the Great Plains.

Several decades passed before criticisms of the obvious weaknesses of American land-settlement policy were recognized by Congress. As early as 1875, for example, President Grant urged that attention be given to the need for different homestead policies in the Plains region. In 1878, Maj. J. W. Powell, in reporting to Congress on the Lands of the Arid Region (*305*),[3] pointed out the need of a special land policy for the western plains, and proposed a pattern of land use, with homesteads of 2,560 acres, which in many of its basic aspects is similar to that being encouraged by governmental agencies today. The unfortunate results of the homestead policy on the western plains became common knowledge, but no change in the policy was accomplished that met the criticisms or the realities of the situation.

The same resistance to change was evident in regard to the control of grazing on the public domain. The Public Lands Commission in 1904 reported on the overgrazed condition of the range and other undesirable consequences of the lack of any control over the use of the public domain. No action was taken—owing in part no doubt to the fact that politically powerful cattle interests believed the prevailing situation favorable to them. In 1916, when legislation governing the public lands was again under discussion, little attention was paid to the opinions of experts or to the experience of the United States Forest Service, which had proved the value of regulated grazing. Instead of adopting a constructive land policy, the Nation contented itself with the alternative of the 640-acre stock-raising homestead. The general inadequacy of this policy has already been suggested.

Recognition of the excessive waste of land resources during the latter part of the nineteenth century, however, resulted in one important change in American land policy. That was the development of the conservation movement, which succeeded in saving some of the Nation's forest and mineral resources for careful exploitation in the public interest. An act of Congress in 1891 authorized the reservation of forest lands in the public domain, and large acreages were set aside as national forests under Presidents Harrison, Cleveland, and Theodore Roosevelt, while other areas were reserved for their mineral resources. Later the program of conservation was expanded to permit public purchase of small amounts of land for reforestation, wildlife refuges, and recreation areas.

The measures promoted by the conservation movement were the outstanding developments in American land policy previous to 1933. Perhaps the greatest contribution of the movement was its cultivation of an aroused public interest in the matter of land resources, for in this respect it paved the way for the broader understanding of land problems that followed. The conservation movement, however, did not effectively answer or cope with the outstanding problems of agri-

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

cultural land use and tenure. The movement was concerned primarily with nonagricultural lands, whereas the most serious social and economic problems arising from land use have come about as the result of conditions of agricultural land occupancy and use. Moreover, the conservation movement concentrated upon the public ownership of land as the remedy for waste and abuse. Private owners, whether of forest or agricultural lands, remained largely unrestricted in their exploitation and misuse of land resources.

During the first years of the administration of Franklin D. Roosevelt the basis of a new land policy for the United States was formulated. The obsolescent homestead policy was laid in its grave with the passage of the Taylor Act, and systematic surveys were undertaken to determine the true nature and extent of the economic and social problems which a century and a half of thoughtless exploitation of land had left on the Nation's doorstep. The methods whereby these problems are being attacked form the basis of other articles in this Yearbook. Suffice it to point out here that the new land policy, like the old, is based upon the force of circumstance and the influence of our contemporary environment on our slowly changing ways of thinking. The frontier nation had to destroy the wilderness to make way for civilization; the mature nation of today must conserve its resources and maintain a careful balance with nature in order to preserve the vitality of its civilization. Contrasted with the eighteenth century's need to break down the feudal restrictions upon land tenure is our modern need to recognize anew the tremendous social responsibilities inherent in the ownership of land, and to develop democratic mechanisms to protect the permanent public interest in our land resources. Less restricted in emphasis than the older conservation movement, the new programs emphasize wise land use, which includes considerations of social and economic adjustment as well as the preservation of natural resources. Likewise, land problems are being attacked on all fronts—not only those which concern the conservation of forests, minerals, and wildlife, but also the complex social and economic aspects of agricultural land tenure and use.

THE SYSTEM OF INHERITANCE[4]

The American colonists experimented with several systems of holding and inheriting land. Particularly common among the colonies, outside of New England, was the old European system of primogeniture and entail, under which the eldest son inherited an inalienable right in the real estate to the exclusion of all other children. Many of the colonists had observed in the mother country how this system of inheritance established a leisure class composed of large proprietors who looked to the soil for complete support. Such a landed aristocracy being incompatible with the spirit of American democracy developing at the time of the Revolution, the young democratic Nation soon legally dispensed with many of the remnants of the feudal land systems, largely doing away with primogeniture and entail.

The colonists thus soon came to believe that the interests of a democracy could be served best if the laws of inheritance tended toward

[4] Acknowledgment is made to Marshall Harris and H. A. Turner, of the Bureau of Agricultural Economics, for assistance in preparing this section.

equality in the shares of the various heirs. They assumed that it was a prerogative of the State to control absolutely the manner in which landed property descends in case of intestacy. Since that time the several States have generally followed the same assumption and have restricted in some measure also the power of bequest. Under this philosophy the State can change the inheritance laws in any manner that may be deemed advisable, and may even forbid inheritance, requiring that the property of the deceased escheat to the State. The founding fathers, however, recognized that the individual should be permitted to pass his property on to his heirs largely as he sees fit. The American system of inheritance, therefore, permits the individual to transfer his property as he pleases by a will subject only to certain specified rights of a surviving spouse and various minor regulations, except that the owner may not entail the estate beyond the life of a living person or persons plus 21 years. In the absence of a will, the laws of the several States determine the manner in which the property is to be divided.

Although inheritance statutes vary considerably from State to State, they generally recognize the rights of the spouse, lineal descendants, father and mother, brothers and sisters, and so on. As among the heirs in each of these categories, the property, the income therefrom, or the proceeds from the sale thereof, is usually distributed equally. When some heir demands that the property be distributed, the courts generally take the attitude that if it cannot be divided without materially impairing its value, it shall be sold as a unit and the proceeds divided among the heirs. The statutes of the several States regulating the inheritance of property left intestate have also had a marked influence upon the manner in which property is transferred by will. Wills, therefore, more or less generally provide for an equal distribution of the property among the several heirs, even though this is not legally necessary.

The inheritance laws have thus helped to prevent the development of a landed aristocracy dependent upon the soil. This influence, coupled with the predominance of other means of investment in an industrial society, has served to prevent the ownership of land in the United States from becoming a prerequisite for entrance into certain social strata or into politics, as was long the case in many older countries.

The absence of numerous large landed estates has had a beneficial influence in the development of a well-balanced agriculture, particularly in the maintenance of the American ideal—the family-sized farm. It has been argued that large estates can be cultivated more efficiently than if they were divided into smaller ones. American experience with large-scale operation has not confirmed this belief. The experience of England likewise does not afford conclusive evidence that inheritance laws, which have in the past tended to perpetuate large estates,[5] make for sound economic and social conditions. Under such circumstances the total agricultural production of England has been significantly smaller than would have been possible if the large estates were divided into family-sized farms. Great Britain's experience during the World War forced recognition of the need for a system of

[5] Recent changes in English inheritance laws and taxes are making some adjustments in this situation.

land tenure that would permit the Nation to become more nearly self-contained in food supply. While the larger English estates have been customarily subdivided into smaller units and leased to tenants, the system contributed to the development of a large agricultural proletariat characterized by uncertainty of employment and low living standards. France, however, has followed the other extreme. Her inheritance laws have fostered excessive subdivision of real property until many farms are far too small. France has been able, however, to supply a significant proportion of her food requirements, although frequently at the expense of a lower living standard for her agricultural workers. The American inheritance laws have tended to establish a medium between these two extremes. Neither the restricted aggregate production and potentially bad social conditions of the large landed estates nor the inefficiency and insufficiency of the small peasant holding are favored by our system of inheritance.

Our inheritance laws, however, have not been entirely free from undesirable effects. Their imperfections are becoming more apparent now that the days of homesteading and free land grants are definitely ended and the transfer of property through some form of inheritance or gift plays an ever-increasing role in our national economy. This is particularly significant since during recent years about one-fourth of the change in ownership of farms has occurred in connection with some form of inheritance or gift.

The philosophy of distributing the property equally among the several heirs, as laid down in the inheritance laws and as followed in many wills, has resulted in subdivision into uneconomic-sized units in some parts of the country. This is largely the result of specific provisions in wills, or to a high degree of economic isolation which has made it necessary that the land be divided among the heirs, farming being the only occupation open to the children. This latter tendency has been particularly prevalent in the southern Appalachian highlands. There the property has been divided and subdivided until the farms are entirely too small and the land is used for purposes to which it is not adapted. Somewhat analogous conditions have developed in other sections. In some of the counties of Utah and eastern Idaho the land has been subdivided among the several heirs in such manner that there has developed in two generations a scattered small-field system somewhat comparable to that of Europe in the Middle Ages. This has come about largely as a consequence of the desire to distribute good and poor land equally among the heirs even though the holdings consist of six or eight parcels each separated by a mile or more (*22*).

In all areas of the country where the American system of inheritance has caused subdivision to proceed too far, land unsuited for cropping has been brought into cultivation. Much of the land on the small farms has been planted year after year to intertilled crops. Other land unsuited for farming has been cropped for a few years and then permitted to revert to woodland pasture. Pasture land has been overgrazed. Forests have been cut down and no system of reforestation has been followed. Much soil wastage through erosion has occurred, and rural poverty due in large part to soil deterioration and uneconomic-sized holdings has resulted.

In other areas of the country the philosophy of permitting the individual to will the property largely as he sees fit has resulted in a tendency in the opposite direction. It has made possible the development of some fairly large estates controlled generation after generation by the same family. There is developing in connection with these estates an attitude of a landed aristocracy. This has resulted in two antisocial influences: (1) The development of a landed leisure class, and (2) the development of absentee ownership and farm tenancy. The implications of the first evil are largely social. It has reacted only indirectly upon the use of soil resources. Absentee ownership of land and farm tenancy on these large estates have had a direct adverse influence upon land-use and farm-management practices.

The development of absentee ownership and farm tenancy has also resulted from the manner in which average-sized estates are inherited. If the widow has not been willed a life estate, she generally inherits one or both of two things—a homestead or a dower. In any case she usually maintains an interest in the estate during her lifetime. Usually she rents the land, not being in a position to operate it herself. In case there is no widow, the children or the other heirs often desire to hold the estate as a unit and rent it to one heir or to some other tenant farmer. Even in case the heirs desire to sell the farm and divide the proceeds therefrom, it is often a year or two before the court procedure permits the completion of the transaction. During this time the farm is usually operated by a tenant. Occasionally the heirs agree to a division of the property whereby one heir will receive the farmstead and the adjoining land, and will rent from the remaining heirs their respective parcels.

If one of the heirs operates the farm, the tenancy system which results may or may not be socially desirable. There are numerous cases where the tenant heir who remains on the farm has been able to develop a productive system of farming, to conserve the soil, and to maintain an American standard of living. Instances of opposite tendencies are also frequent.

A study of inheritance in three Iowa counties during a 10-year period indicates that approximately one-third of the testators bequeathed life estates in their acreages. The recipients of these life estates averaged 65 years of age. Since they often have little or no interest in the property except as a means of income during their lifetime, and since their average age is so advanced, the system of tenancy arising under such circumstance is often particularly bad. If the tenant has an interest in the property, he is usually certain that there will be a significant change in his relationship to the property upon the death of the holder of the life estate.

If one of the heirs desires to buy the farm rather than rent it, he must quite frequently pay more for it than it would bring in the open market, for the other heirs are likely to believe that the home farm is the best farm in the community, and that it should bring the highest sale price. The consequences of heavy mortgaged indebtedness resulting from such circumstances in many cases have been as serious as the unsatisfactory leasing arrangements.

A more widespread consequence of our inheritance system is the continuous flow of wealth from rural to urban areas. This is a result

of the usually large net migration of farm youth to the cities. It is not offset by the inheritance of urban wealth by rural heirs, for the direct heirs are likely to have migrated with the parents to urban areas; and even if they have not, are prone to leave the country when sufficiently wealthy to maintain an urban standard of living. The tendency for inheritance to transfer wealth from rural to urban ownership is much more widespread than is commonly believed. A study in four townships in Whitman County, Wash., revealed that heirs living in cities inherited 82 percent of the farm property passing by inheritance during the period 1920–30 (*474*). It may be expected that the flow of wealth from the country to the city will continue as long as the line of migration leads to the cities and as long as the heirs moving to the cities take with them rights to income produced in the country, whether in the form of annual rentals or of mortgage payments.

Detailed information regarding the nature and extent of the transfer of agricultural property through inheritance is exceedingly scarce. Studies of the social and economic consequences of our system of inheritance comprehensive enough to indicate dangerous tendencies existing in the institution of inheritance have not been made. This line of investigation must be explored more in detail before adjustments can be made in the shortcomings outlined, and before other maladjustments can be uncovered. The powerful influence of inheritance laws applicable in rural areas on the general social welfare should be more clearly recognized. As a nation we cannot with safety long neglect serious consideration of the economic and social significance of this subject.

LAND VALUES, LAND SPECULATION, AND LAND SETTLEMENT[6]

Extensive changes in the value of rural land, more or less associated with speculation, have been a notable characteristic of American rural life and have exerted a profound influence upon it. A highly speculative attitude toward land has been traditional in the United States.

> America from its inception was a speculation. It was a speculation to Columbus. It was considered as a speculation by the kings of Spain, France, and England. They looked upon it as a source of riches in gold, silver, and pelts (*332*).

Instances of speculation in land existed in ancient times. Land speculation, however, does not flourish in a self-sufficing economy, or wherever economic conditions are essentially static. It was not, therefore, a prevalent phenomenon during the Middle Ages. It is predominantly an outgrowth of capitalism, and in rural areas has been most prevalent in the newly settled countries of the world where the ownership and occupancy of land are less stable than in countries where they are dominated by custom. Adoption of allodial tenure[7] in fee simple early in the history of the United States further stimulated speculative buying and selling in the largest area of readily salable land in the world. The settlement and development of this

[6] Acknowledgment is made to John B. Bennett of the Bureau of Agricultural Economics for assistance in preparing this section.

[7] That is, unrestricted ownership, free of rent or feudal obligation; the opposite of feudal tenure.

body of land proceeded at a rate far in excess of that which took place on any equal area of the globe. It is no wonder, then, that land speculation has played such a prominent part in the economic development of the United States.

With an economic system characterized by private property in land, free markets, and a high degree of freedom for individual enterprise, some speculation in land is inevitable, particularly when population is rapidly increasing, new lands are being developed, and other basic changes in economic conditions are taking place. Its social advantages and disadvantages cannot be separated from the broader questions of the advantages and disadvantages of private property in land. In the United States, however, an excessive degree of land speculation appears to have had certain unfavorable effects upon the pattern of land prices, land settlement, land ownership and tenancy, and land use.

Table 1.—*Index of value per acre of Missouri farm real estate, 1820–1930* [1]

[1912-14=100]

Year	Index	Year	Index	Year	Index	Year	Index
1820	3.7	1848	6.2	1876	20.0	1904	60.5
1821	5.9	1849	7.2	1877	17.6	1905	60.1
1822	4.8	1850	6.6	1878	18.0	1906	67.6
1823	9.4	1851	7.8	1879	15.7	1907	66.2
1824	3.4	1852	9.1	1880	17.5	1908	71.6
1825	4.2	1853	9.8	1881	18.9	1909	86.4
1826	4.5	1854	10.4	1882	21.8	1910	87.2
1827	3.8	1855	10.0	1883	23.3	1911	98.0
1828	5.1	1856	14.1	1884	27.4	1912	95.2
1829	3.9	1857	12.0	1885	30.8	1913	104.3
1830	4.0	1858	10.1	1886	25.4	1914	100.5
1831	5.8	1859	13.8	1887	30.8	1915	104.9
1832	6.3	1860	11.8	1888	32.7	1916	112.1
1833	6.8	1861	10.6	1889	34.0	1917	112.6
1834	8.4	1862	9.4	1890	31.4	1918	129.8
1835	6.0	1863	9.0	1891	36.2	1919	145.9
1836	10.3	1864	10.5	1892	36.2	1920	164.0
1837	8.9	1865	13.3	1893	37.2	1921	145.5
1838	8.6	1866	14.3	1894	41.2	1922	125.7
1839	9.5	1867	16.1	1895	35.7	1923	120.4
1840	13.3	1868	17.2	1896	41.0	1924	114.7
1841	9.0	1869	16.2	1897	37.2	1925	112.2
1842	8.9	1870	17.7	1898	38.4	1926	103.8
1843	7.8	1871	21.8	1899	36.7	1927	109.0
1844	7.3	1872	22.3	1900	41.1	1928	101.3
1845	10.0	1873	17.5	1901	45.3	1929	99.2
1846	6.2	1874	19.2	1902	49.2	1930	90.8
1847	6.8	1875	19.2	1903	50.6		

[1] Prepared by the Division of Land Economics from data collected under cooperative agreement between the University of Missouri and the Bureau of Agricultural Economics.

The historic trend of land prices in the United States has been upward. This has been due to a constantly increasing demand for land occasioned by a rapidly growing population. Over a period of a century, land prices may have increased several thousand percent from the low levels that prevailed in the earlier years of occupancy. This is illustrated in table 1, which shows the index of the value of farm real estate in Missouri from 1820 to 1930. In a new country, land prices may double or triple within a few years. This happened in Missouri, for example, between the years 1820 and 1823. In this respect land differs from such commodities as cotton or wheat, pro-

duction of which continues from year to year and for which there is no definite prospect for long-time shifts in average prices, either upward or downward.

The tendency of population growth to raise land values, to be sure, may be offset for considerable periods by improvements in agricultural technique or admission of imports from abroad, although neither factor would affect the value of all land equally. Higher taxes on land may also be a deterrent to increasing values.

It is doubtful if the tendency toward increase of land prices over a long period of years, as distinct from increase over a short period, can be attributed in any material degree to speculation. Apologists for speculation are probably correct in arguing that in the long run there are as many speculative sellers as speculative buyers, and that in the long run their influences tend to neutralize one another.

One effect of speculation probably is to anticipate long-time increases in land prices so that they are realized earlier than would be the case if land buying were limited to actual settlers. This means that in many instances professional land speculators acquire the gains that might otherwise have been obtained by the settlers themselves. Another tendency is for speculation to overestimate the amount of increase justified by economic relationships, and in the inevitable readjustment the prices of land may be carried unduly far in the other direction.

In the United States population growth continued at a rapid rate for more than a century. The popular opinion was that it would continue unabated for many more years. This opinion had forced prices of land to levels not justified by their current earning power in the years just prior to the World War. The speculative overvaluation of farm land, as it affected Iowa land prices, is indicated by table 2, which shows the proportion of land values represented by capitalized net rent, on land rented for cash. If net rental values may be taken as a measure of the earning capacity of land, then the true value of land should be equivalent to the net rent capitalized at the prevailing rate of interest. When land is held at prices in excess of the capitalized net rent, it may be said to be overvalued in relation to its current earning power. As shown in table 2, farm land rented for cash in Iowa began in 1902 to be valued in excess of the capitalized net rental value. By 1913 the capitalized net rent represented only 54 percent of the land value. These high land values were reached before any effects of the World War upon prices of farm products had been felt or even anticipated. They appear to have been justified solely by the belief that continued growth in population would raise the earning power of the land at some future date.

Speculative overvaluation of land was greatly enhanced during the World War. The proportion of land values represented by net rent on Iowa farms rented for cash dropped to a low point of 44 percent in 1920. It rose gradually after that year, because land values fell gradually, as they did in the country as a whole, until 1933, when the average value of farm land in the United States was 27 percent below the 1912–14 average. The drop in land values appears to have been due largely to the financial difficulties that plagued farmers during the post-war agricultural depression years, especially the severe depres-

sion of the early 1930's. But the spreading realization that population growth in the United States is slowing down and that, barring wholesale lifting of immigration restrictions, it probably will cease altogether within a few years, may have been partly responsible. Farm land values, at least in the North Central States, are still relatively high in proportion to the earning power of the land (table 3), if one takes a percentage return of 5½ percent as a standard.

Table 2.—*Approximate net rent per acre and proportion of current value of farm real estate rented for cash in Iowa, based on current rents, 1900–36* [1]

Year	Average value per acre of cash-rented land	Gross cash rent per acre	Taxes plus estimated depreciation and repairs per acre	Approximate net rent per acre	Ratio of rent to value: Gross rent	Ratio of rent to value: Net rent	Net rent capitalized at 5½ percent	Proportion of value represented by capitalized net rent
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Percent*	*Percent*	*Dollars*	*Percent*
1900	42	3.29	0.42	2.87	7.8	6.8	52	124
1901	47	3.30	.44	2.86	7.0	6.1	52	111
1902	54	3.31	.49	2.82	6.1	5.2	51	94
1903	61	3.39	.55	2.84	5.6	4.7	52	85
1904	66	3.52	.59	2.93	5.3	4.4	53	80
1905	66	3.57	.58	2.99	5.4	4.5	54	82
1906	66	3.65	.57	3.08	5.5	4.7	56	85
1907	71	3.75	.60	3.15	5.3	4.4	57	80
1908	76	3.88	.64	3.24	5.1	4.3	59	78
1909	80	4.07	.66	3.41	5.1	4.3	62	78
1910	87	4.22	.70	3.52	4.9	4.0	64	74
1911	97	4.30	.79	3.51	4.4	3.6	64	66
1912	106	4.47	.84	3.63	4.2	3.4	66	62
1913	120	4.60	1.04	3.56	3.8	3.0	65	54
1914	125	4.95	1.06	3.89	4.0	3.1	71	57
1915	135	5.14	1.13	4.01	3.8	3.0	73	54
1916	153	5.47	1.23	4.24	3.6	2.8	77	50
1917	160	5.73	1.35	4.38	3.6	2.7	80	50
1918	175	6.38	1.42	4.96	3.6	2.8	90	51
1919	191	7.17	1.64	5.53	3.8	2.9	101	53
1920	255	8.19	2.03	6.16	3.2	2.4	112	44
1921	236	10.48	2.14	8.34	4.4	3.5	152	64
1922	188	7.42	2.18	5.24	4.0	2.8	95	51
1923	170	7.39	2.12	5.27	4.4	3.1	96	56
1924	164	7.38	2.15	5.23	4.5	3.2	95	58
1925	154	7.39	2.07	5.32	4.8	3.4	97	63
1926	153	7.55	2.10	5.45	4.9	3.6	99	65
1927	149	7.69	2.15	5.54	5.2	3.7	101	68
1928	142	7.75	2.15	5.60	5.5	3.9	102	72
1929	140	7.79	2.22	5.57	5.6	4.0	101	72
1930	130	7.77	2.20	5.57	6.0	4.3	101	78
1931	114	7.43	1.97	5.46	6.5	4.8	99	87
1932	93	6.08	1.71	4.37	6.5	4.7	79	85
1933	70	4.46	1.42	3.04	6.4	4.3	55	79
1934	78	4.99	1.42	3.57	6.4	4.6	65	83
1935	81	5.21	[2] 1.45	3.76	6.4	4.6	68	84
1936	88	5.70	[2] 1.50	4.20	6.5	4.8	76	86

[1] All data preliminary. From Stauber and Regan (*383, p. 20*).
[2] Taxes per acre are estimated for 1935 and 1936.

Land speculation in many instances produces a scattered pattern of settlement. Evidence of this tendency may be seen in the peripheries of any city, where a solid residential development may extend to a certain street, break off abruptly, and begin several blocks farther on. The vacant blocks in most instances of this kind are held by speculators at such high prices that both construction companies and individuals buying lots for their own use go farther out from the center of the city, to areas where land is lower priced.

Table 3.—*Approximate capitalized net rent and proportion of current value of farm real estate rented for cash in selected States based on current rents, 1921–36* [1]

Year	Net rent capitalized at approximate mortgage-interest rates [2]							Proportion of value represented by capitalized net rent						
	Minnesota	Missouri	North Dakota	South Dakota	Nebraska	Kansas	West North Central States [3]	Minnesota	Missouri	North Dakota	South Dakota	Nebraska	Kansas	West North Central States [3]
	Dol.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1921	80	92	23	58	76	54	97	61	85	58	64	71	71	66
1922	59	64	18	36	54	42	64	53	74	58	52	60	67	54
1923	51	62	18	31	51	39	62	49	78	62	55	60	65	57
1924	52	60	17	29	49	37	61	51	78	63	54	60	64	58
1925	50	58	15	29	49	38	61	52	82	63	57	63	67	62
1926	50	57	16	28	50	37	62	52	81	67	57	64	65	63
1927	52	55	15	27	49	37	62	55	81	63	59	64	65	65
1928	52	54	16	30	52	37	63	59	83	67	68	68	65	68
1929	52	54	16	30	53	39	63	61	86	70	70	71	68	69
1930	51	52	15	30	54	38	63	64	88	68	71	73	70	74
1931	49	46	13	30	54	34	61	70	87	68	81	76	71	80
1932	45	39	11	23	44	27	50	76	89	69	79	77	73	81
1933	34	29	9	19	31	22	36	69	91	60	79	72	67	75
1934	38	32	11	19	33	25	41	76	91	65	79	73	74	79
1935 [4]	39	32	10	18	32	25	42	75	89	62	78	73	74	79
1936 [4]	43	36	10	20	40	27	48	77	9[illegible]	62	85	81	76	84

[1] All data preliminary. From Stauber and Regan (*383, p. 21*).
[2] Approximate mortgage-interest rates used: Minnesota, 5¾; Missouri, 6; North Dakota, 6½; South Dakota, 6; Nebraska, 5¾; Kansas, 6 percent.
[3] Weighted average; includes Iowa.
[4] In obtaining approximate net rents, taxes per acre are estimated for 1935 and 1936.

Contemporary documents indicate that land speculation in the early years of the Nation's development produced such a scattered pattern of rural settlement (*163*). The speculators frequently were on the frontier only a short distance behind the trappers and considerably ahead of the settlers. They bought vast contiguous tracts, as in the case of the Ohio and Scioto companies, or acquired the most desirable tracts in many localities. In either event they were likely to advance their asking prices to points higher than the auction prices of remaining public lands in the vicinity or farther west. The first actual settlers, therefore, tended to go around the speculatively held lands and settle on poorer lands in the locality or move farther into the western country.

Eventually further settlement filled in the gaps caused by the speculators, for either the demand for land became so great as to permit the speculators to realize their asking prices, or they were forced by the weight of their carrying charges to reduce prices. But as long as a scattered pattern of settlement persisted, it added to the cost of public services and prevented the full realization of the benefits of compact community development. In some areas more recently settled, the scattered pattern of settlement induced partly by land speculation still persists.

The earliest land-disposal laws of the Federal Government, which limited sales to minimum tracts far larger than a farmer could till with

the primitive tools of those days, favored the concentration of land ownership into a few hands. These restrictions were soon removed and it became possible for the actual settler to purchase land in units of family size. Nevertheless, sales of public land at auction, with no limitation on the quantity sold to one person or company, continued until 1891, almost 30 years after the Homestead Act was passed. The Homestead Act itself, moreover, through fraudulent entries, was frequently used to assist large landowners in enlarging their holdings. Furthermore, large grants, aggregating over 100,000,000 acres of public land, were made to corporations to encourage the construction of canals, wagon roads, and railways. These grants were also a vehicle of extensive speculation, as were the bounty grants to veterans after the provision for negotiability was introduced.

Most of the large purchases of public land were made for speculative purposes. The concentration of lands in relatively few hands, which resulted initially from these purchases, has been considerably dissipated by sales to actual settlers; however, many of these holdings still remain partially intact.

During more recent times, speculation has tended to concentrate land ownership in the hands of absentee owners in other ways than the direct purchase of public lands from the Government or from homesteaders. When, during boom times, speculation raises the price of farm land far beyond the price justified by the earning power of the land, many farmers are discouraged from buying land; but many others buy farms at these exorbitant prices, making substantial down payments and giving mortgages for the unpaid balances. Banks, mortgage companies, and insurance companies invest in the mortgages. Following the collapse of such a boom, the buyers are unable to meet their payments and their mortgages are foreclosed. Title to the land passes into the hands of absentee owners—the creditor agencies—and the former owners revert to the status of tenants. At the beginning of a recovery period the credit agencies usually make an effort to dispose of their farm holdings. Many of the buyers at such a time are farmers, but it is at this stage of a period of economic recovery that the urban investor, usually an individual business man, is frequently found in the land market, purchasing farms for speculative purposes in competition with actual farmers.

When absentee landlords are seeking to profit primarily from speculative sales rather than from operating revenues from their farms, they are likely to contribute to deterioration of their properties. They are not interested in preserving soil fertility, for they hope to sell before deterioration of improvements or soil progresses sufficiently to affect the price of the land.

Farm owner-operators, as well as absentee landlords, frequently are imbued with a speculative spirit. They are interested in their farms as sources of quick speculative profits rather than as means of livelihood over a long period. Their attitude results in the same kind of neglect of improvements and soil fertility as is found among the speculative absentee owners.

In short, land speculation has exerted an influence adverse to conservation and economic stability in rural areas. This influence is so serious a detriment to rural welfare that measures should be adopted

that will tend to lessen speculation in farm real estate and confine fluctuations in its value at least to those justified by variations in net returns attributable to the use of land and improvements.

One means of curbing land speculation would be to levy a special tax on income from land rents. Such a tax would tend to discourage absentee ownership of land, either as an investment or while awaiting a rise in values, and would encourage land ownership by farmer operators. It would probably also operate to shift investment activity from ownership of farm land to lending on mortgages and would tend to encourage the operation of absentee-owned farms by managers or hired labor. The latter eventuality would offer a fairly easy way of avoiding the tax but would be less feasible for the short-time speculator than for persons buying land with intent to hold it for considerable periods. A second application of the taxing power to this problem would be a levy upon the increase in the value of land between the time of purchase and the time of sale. This is discussed in a later article dealing with taxation (p. 163).

Aside from the use of the taxing power, however, governments could do much to discourage land speculation through land-settlement and credit policies designed to develop a system of land tenure based on continuous, secure, family income rather than on the hope of speculative gain (*429*).

PUBLIC AIDS AS A CAUSE OF LAND MISUSE

Public aids to individuals and to rural communities frequently cause or perpetuate the misuse of land. Some of these public aids are of local origin, but most of them arise from outside of the areas where the land is being misused. Local governments are relying more and more on sources of revenue other than their local general property taxes to support their public services, their institutions, and their relief of the poor. These nonproperty-tax revenues are collected and disbursed largely by the States and the Federal Government. Concurrently the credit requirements of rural communities are being supplied more and more by public credit agencies, sometimes State but principally Federal.

The needs for such outside aids are especially great in the areas in which attempts are being made to farm large acreages of land poorly suited to agricultural use. The contributions of State and Federal funds to the people in such areas frequently far exceed the contributions to State and Federal revenues which originate in the areas. Outside aids take the form of State subventions to local governments for roads and schools, Federal aid for highways, Federal emergency feed and seed, crop, and drought loans, Agricultural Adjustment Administration rentals and benefits, and Federal relief allotments.

Such outside aids sometimes reach startling proportions. As has been noted elsewhere in this Yearbook,[8] the total of Federal funds going into certain drought areas in the Great Plains during a recent 3-year period was more than $200 per capita. In the cut-over sections of northern Michigan, as far back as 1916, 31 counties received more from the State school fund than they contributed in State taxes (*375*).

[8] See The Great Plains and Other Dry-Land Farming Regions, p. 68.

Many of these aids are justified. Taxation of incomes and property to provide revenues for a variety of public services and for relief, benefit payments, etc., operates to level off, to some extent, maldistribution of wealth. Outside contributions to the provision of such services in certain geographic areas usually indicate a concentration of people in these areas who are in such economic straits as to need more services than they can provide locally from their own resources. Merely to withdraw outside contributions without doing anything to alter the conditions that make them necessary would only create suffering and destitution and perpetuate ignorance from lack of schooling.

There are, furthermore, other legitimate reasons for outside public payments to many rural areas. State and Federal aids to rural highways can be justified on the basis of the extensive use of these facilities by people, both urban and rural, from outside the communities in which the aids are used. Some outside aids for rural schools are justified in most cases on account of the trend of net migration from rural to urban areas, which provides the cities, towns, and villages with large numbers of young adults, most of whom have received a common-school education in the country and many of whom are high-school graduates. The supplementary report of the Land Planning Committee to the National Resources Board (*434*) estimates that the contribution which the farming people of the Nation made to urban areas through the net farm-to-city migration of 6,300,000 persons during the period 1920–30 amounted to $14,000,000,000.[9] Again, since the real burden of taxation in many instances does not fall upon those who actually pay the taxes, there is likely to be a great deal of indirect taxation upon the people in the rural areas which does not show in statistics of actual tax payments. Such indirect taxes would offset to some degree the State aids and subventions to the people in these areas. Similarly, indirect Federal taxes offset to some extent such Federal aids as relief or crop loans.

The problem, therefore, is not simply one of withdrawing outside public contributions to the poor-land areas. It is true that programs for correcting misuse of land and maladjustments between land resources and population in these areas should reduce the need for such contributions. These programs are likely to require several years for completion, however, and in the interim the continuance of some outside aids to the areas will be necessary. The problem then becomes one of so administering the aids as not to perpetuate or create anew the misuses of land which have brought about the economically and socially undesirable conditions. As now administered, some of these aids do tend to do this.

A number of the more common public aids to land-use problem areas and the ways in which they tend to prevent desirable changes in land use and occupancy are discussed in the following paragraphs.

Relief

The most common form of poor relief is direct relief (the dole) from Federal, State, or private sources. Federal direct relief has been extended since 1933 by the Federal Emergency Relief Administration

[9] This figure assumes a cost of $2,000 to $2,500 for rearing and educating a child to the age of 15.

and the Works Progress Administration. These agencies and the Civil Works Administration also have made grants for work-relief projects.

Direct and work relief has been partly a phenomenon of the depression, constituting a part of the cost of maintaining an economic system that has been subject to periodic break-downs. It has been especially heavy, however, in some of the land-use problem areas.

As records of the number of families receiving unemployment relief became available on a nation-wide scale in 1933, it was evident that most of the areas with exceptionally high relief rates were rural regions in which the majority of the people lived in the open country, or villages and towns of fewer than 5,000 inhabitants. Study of county relief rates for several consecutive months revealed well-defined rural areas in which many counties reported 20 to 30 percent of their families receiving relief . . . Further study made it possible to outline six homogeneous areas for special study. They were the Appalachian-Ozark, the Lake States Cut-Over, the Short-Grass Spring Wheat, the Short-Grass Winter Wheat, the Western Cotton and the Eastern Cotton areas (*27*).

There was no practicable way of avoiding high relief payments in these areas during the recent emergency, when a severe economic depression was superimposed upon the basic maladjustments between their human and their material resources. On the other hand, long continuance of such relief payments will not only obscure the necessity for fundamental readjustments, but eventually cause the people on relief to be apathetic or opposed to any program of readjustment which would take them off the relief rolls and endeavor to restore their independence. The relief program already appears to have had this effect in some localities. A recent survey of an infertile cut-over area in Louisiana (*370*) revealed that of 92 relief families living in the open country, containing an able-bodied male member between the ages of 15 and 50, and receiving the major portion of their subsistence from agriculture, only 37 families, or 40 percent, were willing to move from the area, even if they were to be assisted in disposing of their present holdings and in acquiring better farm lands or greater opportunities for work in some other locality.

Emergency Credit

Another type of outside aid to land-use problem areas, closely bordering on straight relief in some instances, is the emergency credit extended largely by the Federal Government, the need for which arises from the hazards of farming in areas where the risks are high and heavy losses are sustained. This credit takes the form of drought-relief loans, crop loans, seed and feed loans, rural rehabilitation loans, etc. The total of such loans since 1918 has exceeded $300,000,000.

In certain sections, especially in the South, the emergency loans apparently are used to a considerable extent merely to supplement inadequate local credit facilities, and the rate of repayment is fairly high, but the bulk of the loans goes to areas chronically subject to drought or flood and in many instances constitutes a virtual gift.

These loans, as well as direct relief, may be justified as emergency measures, either to tide farmers over an unusual drought, flood, or hurricane, or to give temporary aid to farmers who eventually should be relocated on land where farming is subject to smaller risks. But

to continue such "emergency" loans year after year merely delays the adjustments in land use and occupancy which must come eventually in the high-risk areas.

Agricultural Adjustment Administration Benefits

Rental and benefit payments under the Agricultural Adjustment Act, although not intended as poor relief, frequently have served as a substitute for relief, especially in the drought areas. On account of the importance of wheat in the Great Plains drought counties, the farmers there were entitled to relatively large benefits under the Agricultural Adjustment Act. The total of such benefits in 105 southwestern counties from the beginning of the program in 1933 to June 1937 was almost $111,000,000. These benefits constituted the major portion of the farm income of many farmers in the drought-stricken counties during the 4 years. Without them, disbursements for direct and work relief in these counties would have been greatly augmented.

Good soil management in the more arid sections of the Great Plains appears to necessitate a considerable reduction of the wheat acreage and the substitution of permanent cover to prevent wind erosion. Under the original Agricultural Adjustment Act, farmers receiving benefit payments for curtailing wheat acreage were still required to plant a specified minimum acreage to that crop. In instances where the benefit payments constituted the chief source of income for the farmers and provided their only means of financing the planting of a new crop, it may be questioned whether the acreage reduction brought about by the payments was as great as might have occurred if the farmers had been left to their own resources.

Under the Soil Conservation and Domestic Allotment Act, there is more leeway in adjusting crop acreages to suit natural conditions than under the Agricultural Adjustment Act, and some compensation can be obtained by a farmer for planting soil-conserving crops, such as perennial grasses.

State Aids and Subventions

People in poor-land areas often require substantial aids and subventions from the State government in order to maintain minimum standards for roads and schools—aids greatly exceeding the revenue derived by the State from such areas in the form of property taxes, gasoline taxes, and other excise taxes.

As indicated before, such aids may be justified by the indirect contributions which the people in these areas make to urban communities. But their administration, coupled with laws requiring local governments to furnish roads and schools to all families within their political boundaries, regardless of the places where they may choose to locate, prevents desirable adjustments in land occupancy and use, and even gives rise to additional maladjustments. For example, in some States it is possible for a settler to locate his family on cut-over land 8 or 10 miles from a town or a school, and then demand that a road be built to his home and that his children be furnished transportation to the nearest school. If the State grants aid in the maintenance of township roads, he may be able to do the repair work required to maintain the road which serves only his farm and be paid $40 a mile per year for

his labor. He may also secure a contract for transporting his own children to school. Many isolated settlers in the cut-over regions are able to maintain a foothold on poor farm land by such practices. Sometimes they have been encouraged by colonization agencies to settle in isolated spots, in order that the resulting provision of additional roads and schools might make the agency's surrounding lands more salable. The result is the creation of a scattered, semi-impoverished community, maintaining even its inadequate public services at high per-capita costs, paid largely from State funds contributed by the people of other sections.

EUROPEAN VIEWS ON LAND TENURE

European Agricultural Land-Tenure Laws

Sixty or seventy years ago the farm-tenure policy of many European countries was very similar to that of the United States. Today this is no longer true.[10]

The European land reforms that were carried through under the influence of the individualist-liberal movement during the latter part of the eighteenth century and the first six decades of the nineteenth century first centered in England, France, Prussia, and Denmark. They were directed toward the liberation of the peasants, the creation of free private property in land, the reorganization of farms and farming practices, the abolition of patrimonial jurisdiction and police power, and the granting of political rights to the peasants. From the leading countries these reforms spread over several other territories, finally covering a large portion of Europe. Simultaneously, also under the influence of the individualist-liberal movement, many important reforms were taking place in other fields.

The major principles of economic liberalism as set forth by the classical economists, notably Adam Smith and Ricardo, and the leaders of the French Revolution are well known. Individual self-interest was considered to be the driving force in economic life and at the same time the main source of national wealth. Free competition was expected to be able to check extreme individualism. In addition, there was a firm belief that the interests of the public would generally coincide with the acquisitive motives of the individual.

Like the famous Declaration of Independence issued by the North American colonies in 1776, the Declaration of the Rights of Man and Citizenry issued by the leaders of the French Revolution in 1789 included freedom in the disposal of property as one of the inalienable rights of the individual. This idea was restated in the subsequent French Constitution and expressed in various other European constitutions of that period. It appeared in the new civil codes of several European countries, in court decisions, and in other statements.

Absolute property rights imply that even the state is barred from interfering with the will of the owner. But the lawmakers did not really intend to create that kind of freedom. They decided to preserve the right of the state to regulate private property in the interest

[10] Only one form of tenure is dealt with here, that of ownership in land, and so far as European farm-tenure laws are concerned, discussion is confined to those of England, Scotland, Ireland, Germany, France, Austria, Switzerland, and the Scandinavian countries.

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of public welfare. Restrictions were added to the high-sounding statements concerning the rights of private property. The French Civil Code of 1804—the so-called Code Napoleon—after saying that "property is the right to enjoy or dispose of objects in the most absolute manner," added "provided that it is not used in a way prohibited by laws and regulations." The German Civil Code of 1896, in stating that "the owner of an object is entitled to use and dispose of it at his discretion and to exclude others from any control over it," qualified this principle by adding "within the limits set by law or the rights of third parties." These qualifications, however, were considered to be of secondary importance. The principal emphasis was on the idea of unrestricted property rights.

What happened in the field of private property in general also occurred in the field of landed property. Here likewise the idea of unrestrained freedom was applied. Accordingly the French Rural Code of 1791 and many subsequent laws and decrees of France and other European countries dealing with land declared the owners of such property to be free of restrictions. Under the influence of these new laws, landed property took on the character of a commodity and became highly mobile, that is, it became freely and quickly usable as collateral in financial transactions.

In England, many of the personal obligations and restrictions on land that existed under feudal tenure were dropped or became mere formalities. Land became freely alienable and subject to debt. The title of fee simple became a form of land tenure under which a landholder could use his land practically at his discretion. Very few restrictions were retained. One of these restrictions, a mere formality, was that the land was still "held of the King."

In many sections of the German territory the institution of superior and subordinate ownership was abolished. Henceforth there was to be only full ownership. Such ownership was granted first to the peasants living on Crown land and later to the operators of farms held in superior ownership by the noblemen and the church. Most of the servitudes and other charges were dissolved. At the same time, a decided stand was taken against any further charges on land of a perpetual character. Here, as in England, the result was a type of private ownership that permitted a high degree of freedom of disposal. There were no restrictions of rank, occupation, or residence on land ownership. The land was to be freely salable and divisible and the owner was to enjoy full freedom in burdening it with debts. In addition, many of the former restrictions on inheritance were abolished. In Prussia, this development reached its final stage with the land legislation passed in 1850.

This unrestricted type of landed ownership brought many important improvements. (1) It set free forces of industry and thrift that have contributed in numerous instances to agricultural progress and to the growth of national wealth; (2) it created in many landholders a strong feeling of responsibility and thereby fostered good management; (3) it made possible many useful shifts in landed property by increasing the divisibility and salability of the land; and (4) it enabled many holders to obtain capital quickly and to carry out useful improvements.

But against these benefits, a list of serious shortcomings must be set down: (1) Unrestricted tenure gave many landholders an independence and responsibility that they were incapable of using wisely, and allowed others to misuse their independence. (2) The use of land as a commodity has led to a great deal of speculation and has caused rapid shifts of landed property from one owner to another. At the same time the free play of the forces of supply and demand has not created or maintained a suitable price structure for land. (3) Free divisibility and the loosening of the laws regarding inheritance have frequently caused excessive subdivision and dismemberment. (4) Elimination of restrictions on mortgaging has been followed by an enormous debt on agricultural land. In numerous cases the landholder has lost practically all of his equity. He owns his holding only nominally and works practically as a wage earner for his creditor. (5) The former attachment of the landholder for his land has disappeared in many instances, and the holding is no longer regarded as a permanent home for the family of the operator.

The movement toward individualism reached its peak in Europe by the middle of the nineteenth century. Thereafter several countermovements of a social or collectivist type set in. These likewise reacted strongly on property concepts in general and on land tenure, in some instances causing changes not less profound than those caused by the adoption of the principle of laissez faire. In Germany, where these countermovements became very strong, the reaction on land tenure has gone further than in any other country discussed in this article.

The idea that the owner of land may deal with his property as he pleases has been pushed more and more into the background, and there has been increasing emphasis on the social function of landed property. New restrictions have been enacted, some of them as early as 1880–1900; more of them since 1914.

Sometimes these restrictions have affected only specific groups of agricultural holdings, sometimes the entire agricultural land structure. In the case of new agricultural units created with state assistance, the imposition of many important restrictions on tenure has become quite general, and the restrictions placed on these holdings in the countries here considered have been very similar in character (*201*).

Outstanding in the new restrictive legislation dealing with particular groups of agricultural holdings is the German Hereditary Holdings Act of 1933. This act applies to the German peasant holdings. It imposes numerous limitations but at the same time establishes important privileges for the peasant class. In order to qualify as a peasant, the operator must be (1) of German blood, (2) a German citizen, (3) an honorable person, and (4) capable of managing his holding in an orderly way.

Requirements as to the ability of the owner to manage the holding in a satisfactory way have been included in all recent land-settlement laws of England, Scotland, Ireland, Germany, the Scandinavian countries, and many other nations. Frequently there has also been inserted the requirement that the holder shall reside at the holding and manage his farm personally. In addition, in numerous instances, the

legislatures have provided that land for new holdings is not to be diverted to other uses without the permission of public authorities.

Present German tenure legislation goes even further than this. Every owner of land under cultivation or land suitable for agricultural purposes is bound to make orderly and efficient use of it. If negligence and misuse are observed, the state is entitled to appoint a trustee, or to compel the owner to rent his land to some one who is able to farm it satisfactorily, or to correct the situation in some other way.

When in 1889 the Danish Government launched a new program of land settlement it included in its underlying legislation the following interesting provisions:

> Property must not be subdivided or combined with other land or consolidated unless such action is approved by the Secretary of Agriculture. The Secretary will approve only if the landholder's application has been recommended by the Parish Council. Subdivision can only be approved if general economic conditions and the general settlement plan of the municipality or similar circumstances make it desirable to use the land in question otherwise than originally granted, wholly or in part. Consent may be given to join the plot to other land if circumstances make it seem advisable to comply with the wish of the holder concerned to extend the scope of his work. However, the holding thus formed must not exceed the maximum size mentioned and the whole plot is then to be considered and registered as coming under the rules of the present law. Permission to exchange a plot or part of a plot for another plot may be granted if, by such consolidation, a more appropriate holding will be established. If a plot is to be exchanged for another plot and the obligations are to be transferred in conformity with this law, assurance must be given that the plot to which the liabilities are transferred is just as good and serves the same purposes as the plot upon which the obligations rested before. The conditions upon which combination and consolidation of the debts to the Treasury may be settled in connection with subdivision, are to be fixed by the Secretary of Agriculture upon recommendation from the County Committee.

Later Danish land settlement acts contain similar provisions. In addition, attention may be called to two more recent Danish enactments dealing with land tenure in general. These are the laws Nos. 106 and 108, adopted on April 3, 1925. Law No. 106 provides that all agricultural holdings comprising an area of at least 1 hectare (2.471 acres) and having an assessed land value of at least 1,000 crowns are to be maintained as individual holdings. Law No. 108 provides that parcels of land shall not be detached from existing agricultural holdings without the consent of the Secretary of Agriculture and regulates the enlargement and amalgamation of small holdings.

The German Homestead Act of 1920 establishes the following restrictions:

> The homestead shall not be subdivided or sold in part without the consent of the land settlement agency. State agencies administering the creation of homesteads (under State homestead acts) may rule that the enlargement, partitioning, the selling and the placement of financial burdens on the homestead as well as the selling of parts of the homestead shall be subject to the approval of a public agency.

Selling of the entire holding is allowed under this act. However, if the settler sells voluntarily or is compelled to give up his holding under the pressure of foreclosure, the land settlement agency has the right of preemption. The same act provides that—

> foreclosure of a homestead because of personal financial obligations shall not be allowed. If the homesteader was in debt when he acquired the homestead, foreclosure may be initiated by entry of a mortgage within one year after the date of acquisition. Should the debt not be terminated within five years after the entry of this mortgage, forced sale may be requested.

Under the German Hereditary Holdings Act of 1933, no foreclosure proceeding is allowed. Forced sale of agricultural products produced on the holdings is allowed only under certain reservations. The certificate authorizing a forced sale must be submitted to the local peasant leader 1 month in advance, and agricultural products that are appurtenances of the holding or are needed for the subsistence of the holder or his family are excluded.

Under the same act selling of peasant land is forbidden. The sale of any farm land, except small parcels below the minimum size set by the law, became subject to public approval through legislation passed in 1918, and further restrictions have been enacted since.

In addition, important restrictions have been imposed on the inheritance of agricultural holdings. Under the German Hereditary Holdings Act of 1933 the rule that there shall be only one heir and that the property shall not be divided (the so-called anerbenrecht) has become applicable to all the German holdings qualifying as hereditary holdings (erbhoefe). This rule finds its counterpart in certain Scandinavian, Austrian, and Swiss regulations. Moreover, it should be noted that a provision prohibiting the division of holdings has also been included in modern English land-settlement legislation.

The German Homestead Act of 1920 provides that the burdening of homesteads with debt charges shall be subject to the approval of the agency establishing the homesteads. It also provides that a limit may be entered in the land register as to the financial burden that may be placed on a given piece of land. Holdings falling under the German Hereditary Holdings Act of 1933 are not subject to debt charges.

In the past, the greater density of population and certain political and economic factors made the need for efficient and intensive land use more urgent in certain European countries than in the United States. These countries had to act quickly when they saw that unrestricted ownership was accompanied by serious shortcomings. In many instances inefficient use or abuse of agricultural land, objectionable diversion of such land to nonagricultural purposes, and undesirable subdivision or enlargement, overburdening with debt, and speculation have been prevented.

Property Rights and Forest Land Management in Europe

A German landowner, asked how he could justify an outlay of about $100 an acre for reforesting stripped coal land, replied that he considered it his duty to leave the property to his successors in at least as good condition as when he took it over. Whether or not the expenditure would earn compound interest or show a profit did not enter into his calculations. This epitomizes the prevailing attitude of enlightened forest owners in much of central and northern Europe.

There are, of course, good reasons for this attitude. The pattern of land use in central Europe had become fairly well crystallized by the end of the Middle Ages. To be sure, it has continued to be subject to adjustments, and minor shifts between crops and forests are constantly taking place. In a general way, however, everybody recognizes the fact that forest land will continue to find its best use in forestry and that most of the agricultural land should remain in cultivation.

Racial differences and political boundaries in Europe have tended in recent centuries to impede the free movement from one region to another that has characterized the evolution of land occupation in the United States. Even if such movement were possible, most of central and western Europe has long been fully occupied. For centuries there has been no land over the horizon to be had for the taking. If the farmer exhausts the fertility of the soil or if the forest owner cuts off the timber he cannot expect to move on to a new area and repeat the process. He must make the best of the land he has, or else seek a new source of livelihood. As a result, the individual proprietor feels attached to a particular piece of land, which may have belonged to his family for hundreds of years.

Owing to the crowded populations and relatively limited land resources, it is imperative that all of the land be used continuously in the ways that will be most productive. National policy cannot permit avoidable waste in land use. This is particularly true under present-day tendencies to seek national self-sufficiency. Misuse of the land and destruction or diminution of soil productivity not only are contrary to the best interests of its proprietors but also harm the community. Land is not regarded as a mere object of speculation or a commodity to be exploited at the whim of the current proprietor. Instead, it is held to be an integral part of the permanent national economy—a part of the heritage of the race. The proprietor is regarded as a trustee for the future generations that must live on and farm the land.

This theory of ownership finds its clearest expression in laws of entail, which require that landed properties in entailed estates be kept intact and be passed on to specified heirs. Although post-war legislation in Germany provided for the abolition of such estates, it was soon found desirable to provide, for forest properties, substitute forms of tenure that embodied practically the same requirements.

Such restrictions are particularly necessary with forest land, because misuse of forests is frequently much more difficult to correct, and the correction takes much longer than is ordinarily the case with crop or pasture land. For forest land to yield a continuous income, a growing stock of timber must be maintained at all times. If the proprietor cuts off or seriously reduces the growing stock he can seldom replace it during his lifetime.

Sustained-yield forestry in Europe is regarded as an enterprise in itself rather than a mere adjunct to a manufacturing industry such as a sawmill or a pulp mill. It is much less common for sawmill and pulp-mill concerns to own timberland than in the United States, or for timberland owners to operate sawmills or other wood-conversion plants. Where a forest owner does operate such a plant, it is usually subordinate to the main enterprise, which is forest-land management, and consequently is commensurate with the sustained-yield capacity of the forest. There are some large industrial forest properties in northern Europe that have been well managed for many years, and considerable areas of farm woodland were acquired by nonresident owners and industrial corporations in Norway, Sweden, and Finland during the latter part of the nineteenth century. For the last 30 years or so the policy in all three countries has been to restrict further

acquisition of forest land by such owners. Recent legislation in Germany also makes it practically impossible to alienate woodland belonging to farms.

There were relatively few small individual forest properties before the sixteenth century, but large numbers of such holdings originated after the French Revolution, through partition of forests previously held in common, and through allotment of woodland to the peasants and villagers to take the place of use rights which they formerly held in the public forests and in forests belonging to the large landowners. Taken as a whole, these small forests, mostly farm woodlands, are the worst managed of any forests in central Europe. They are so small and scattered that systematic management by the individual owners is impossible. Being, in most cases, only a minor part of the farm enterprise, they are generally handled to meet the immediate needs of the farm for fuel wood, pasture, bedding, and other minor products rather than the long-time needs of the community as a whole. Much of the farm woodland has been overcut and overgrazed, and the soil has been impoverished by repeated removal of the organic litter.

A form of forest ownership that is almost if not quite unknown in the United States is the so-called corporation forest, held in common by a group of owners. Ownership usually runs with the ownership of farmsteads or village homesteads and can be transferred only with the other property. These forests, although classed as communal forests, are quite distinct from those belonging to political communes, which are analogous to town and city forests as known in the United States. This form of ownership is more favorable for good forest management than the individual ownership of small tracts. The combined area is usually large enough to be handled on a sustained-yield basis, and to permit the full-time or part-time employment of a trained forester. Moreover, the management of such forests is usually subject to the supervision of State forest authorities.

Although most forest owners with tracts large enough for sustained-yield management are disposed to handle them conservatively, there are some who would not do so if it were not required by law. Nearly all European countries have gone further than the United States in legislation designed to insure decent management of privately owned forest land. The scope of public control varies widely.

The simplest form, and that interfering the least with private ownership, is control over changes in land use. Such legislation usually requires only that a proprietor notify and obtain the consent of a designated public agency before clearing forest land; such consent may be withheld where removal of the forest is held contrary to the public interest. In a few places (Bavaria 1921, Hesse 1923) similar consent must be obtained before afforesting agricultural land.

A common form of interference with private forest management, which has been adopted by most European countries, is designed to prevent practices likely to result in damage to the persons or property of others. This applies especially to forests that serve to protect the soil against erosion, regulate stream flow and run-off, protect against wind and other climatic influences, promote the national defense, or preserve the beauty of the landscape. Some countries go further than this and seek to insure a continuous supply of timber,

either by specifically requiring sustained-yield management, or by requiring owners to employ trained foresters and conform to approved management plans. No attempt is made to dictate what kinds of timber shall be grown or what silvicultural methods shall be employed.

The present trend in most European countries appears to be toward a larger degree of public control over forest-land use. This is being brought about not only through legislation affecting the practices of private owners, but also through the gradual extension of public forest ownership in nearly every country.

WITHIN the broad regions devoted to dairying, corn and hogs, cash grain, and cotton, many local and individual adaptations must be made to suit the soil. Failure to adopt the type of farming best suited to a given area, or failure to have the optimum conditions for success in the particular type of farming adopted—including the right size of farm—may both lead to soil misuse. Again, tenancy, which has grown enormously in this country within the past 50 years, may be good or bad from the standpoint of soil use depending on the leasing system and other landlord-tenant relationships. Such questions are discussed in this article.

The Causes: Defects in Farming Systems and Farm Tenancy

By M. R. Cooper, W. J. Roth, J. G. Maddox, R. Schickele, *and* H. A. Turner [1]

IMPROPER FARMING SYSTEMS AND PRACTICES ON LAND SUITED TO FARMING

According to a recent study (*103*) [2] more than 500 type-of-farming areas and about 400 subtype areas are recognized in the United States. These may be consolidated into 13 regional and 100 subregional type areas (fig. 1). The differences between the areas are due primarily to the character of their physical, economic, and other resources, such as differences in slope, in soil, in climate, and in distance to markets.

Although individuals within an area have in general developed a high degree of uniformity in their farming, within each area may be found farms both large and small, farms with productive and nonproductive soils, and farms with much or little level land. Some of the farms have been under the control of the same family for many generations; others have changed ownership often. Similarly, different forms of land tenure prevail.

Under certain conditions some systems of farming lend themselves readily to soil maintenance, while other systems are conducive to soil

[1] The section headed Improper Farming Systems and Practices on Land Suited to Farming is by M. R. Cooper, Senior Agricultural Economist, Bureau of Agricultural Economics, and W. J. Roth, Principal Soil Conservationist, in charge of economic research, Soil Conservation Service. The section headed Farm Tenancy is by J. G. Maddox, Agricultural Economist, R. Schickele, State Land-Use Planning Specialist, and H. A. Turner, Associate Agricultural Economist, Division of Land Economics, Bureau of Agricultural Economics.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

misuse. Within a given type of farming the degree of maintenance or misuse frequently rests largely with the individual farmer. A system of farming that keeps much of the land in continuous cultivation generally is a destructive system, since too often it does not provide for a return to the soil of much-needed humus and plant nutrients. This is particularly true on land that is rolling or hilly and for this reason subject to erosion. A system of farming, on the other hand, that keeps much of the land in cover, such as grass or trees, is generally protective or actually upbuilding in nature. Unfortunately, it has seemed in many instances in the past that the destructive systems have resulted—temporarily at least and particularly when the land

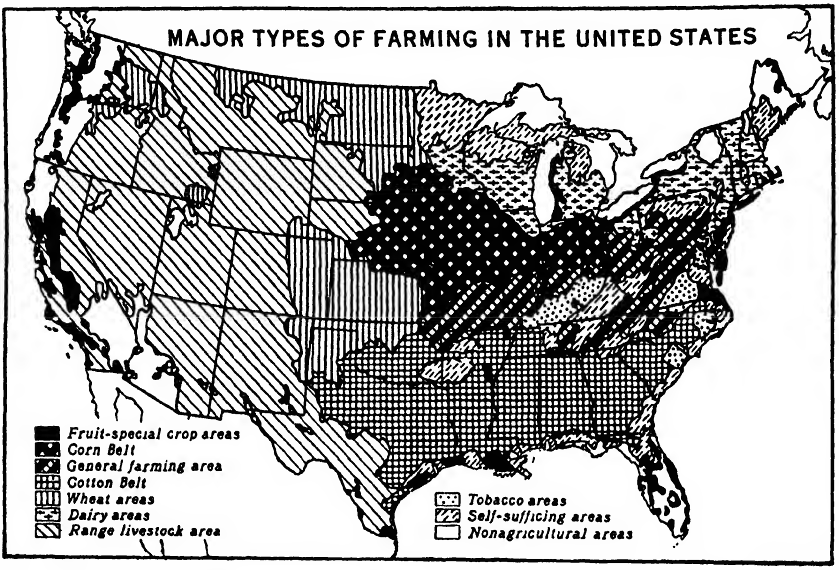

FIGURE 1.—Major regional types of farming in the United States.

was new, fertile, and productive—in higher returns than could be obtained from the protective systems.

The processes involved in maintaining the fertility of productive lands and those involved in rebuilding the fertility of depleted soils are not the same in all sections. In some the problem is relatively simple; in others it is very complex. Systems of farming that by their very nature are soil conserving cannot be adopted as a whole everywhere. This can be clearly illustrated by a regionalized picture of land use and misuse in relation to specific and typical farming systems and practices. Such a presentation will suggest the major problems involved and will throw light on the remedial measures necessary because of the maladjustments that have come to be recognized. The maladjustment may be due to the fact that the system of farming, though sound, is not suited to the region, or to an ineffective size of farm. Either condition will spell defeat and soil misuse.

Dairy Farming Conducive to Soil Maintenance

It is generally recognized that, among other things, a large proportion of forage crops in a system of farming aids materially in preventing soil erosion and soil depletion. In the North Central and Eastern States dairy farming is of great commercial importance. Dairy-farming systems are characterized by a large percentage of land in pasture and close-growing crops such as hay and small grain. They represent an effective adjustment to the combination of climatic, soil, and market conditions in much of the region. Climate precludes the production of large acreages of corn, the land is naturally adapted to pastures and hay crops, and large consuming centers are nearby. Not only is dairy farming in the region relatively profitable, but because of the inclusion in the system of large acreages of hay and pasture and the production of relatively large quantities of animal manure, this system lends itself well to erosion control and soil maintenance. Soil erosion and gullies are consequently relatively unimportant or moderate with a few exceptions.

In the northern part of the dairy belt, as typified by Pine County, Minnesota (table 1), an average of more than 50 percent of the land per farm is in pasture and only 38 percent in crops. Of the cropland about 67 percent is in hay and less than 10 percent in small grain. Farther south in the region, a somewhat smaller percentage of the land is in pastures and a smaller percentage of the cropland is in hay. Small grains are grown more extensively, and the proportion of the cropland per farm devoted to the production of corn is two to three times larger than the proportion devoted to this crop in the northern part of the dairy region. Thus, in the southern part, 27 percent of the cropland of typical dairy farms is in corn as contrasted with 10 percent in corn in the northern part. In both sections the acreage of corn per farm is relatively insignificant if compared with many portions of the central Corn Belt area lying still farther south.

It may be said, therefore, that in this large region the principal type of farming lends itself well to a protective use of soils. But it must be recognized that this system is an adaptation to the climatic, physical, and other factors, and one that cannot be generally adopted in other parts of the United States unless there is a great expansion in the use of dairy products; nor can it, because of local limitations, be extensively adopted in some States even though accompanied by an increase in consumption of dairy products.

It may be said then that soil misuse, when and where it does exist in this vast region, is due largely to variations in the character of the land and to differences in farm practices. Localized systems of farming in which dairying does not play an important part and in which intertilled crops occupy a large part of the land may be instances that present problems of soil maintenance. Neglect and overgrazing of pastures in some sections have resulted in an almost complete extermination of forage plants, and weeds, briars, and bushes have taken the land. Destructive and improper use of wood lots has resulted in land misuse. Improper crop rotations and waste of animal manures have hastened the destructive process on many farms. On many of the poorer lands soil waste has proceeded so far that it is doubtful whether they are worth reclaiming for agricultural purposes.

Table 1.—*Cropping systems on typical farms of indicated types*

State and county	Percentage of all land per farm in— Crops	Pasture	Idleness or fallow	Other	Percentage of cropland per farm in— Hay	Small grain	Corn and/or grain sorghum	Cotton	Tobacco	Other
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
DAIRY FARMS										
New Hampshire—Rockingham	36	50	------	14	80	------	8	------	------	12
New York—Cattaraugus	33	54	------	13	60	15	8	------	------	17
Wisconsin—Taylor	44	44	------	12	63	20	11	------	------	6
Minnesota—Pine	38	56	------	6	67	7	13	------	------	13
New Jersey—Morris	42	42	------	16	34	32	26	------	------	8
Wisconsin—Grant	54	43	------	3	35	29	32	------	------	4
Minnesota—Steele	70	23	------	7	32	26	26	------	------	16
Ohio—Portage	54	38	------	8	29	34	17	------	------	20
Illinois—McHenry	71	25	------	4	25	36	35	------	------	4
LIVESTOCK FARMS (Grain, hogs, beef cattle)										
Ohio—Fayette	62	34	------	4	7	35	55	------	------	3
Indiana—Clinton	71	25	------	4	15	30	55	------	------	0
Illinois—Henry	66	18	------	16	16	36	48	------	------	0
Missouri—Saline	57	29	------	14	20	27	53	------	------	0
Nebraska—Cuming	81	16	------	3	11	31	54	------	------	4
Iowa—Pottawattamie	72	25	------	3	17	26	57	------	------	0
CASH-GRAIN FARMS (Largely wheat)										
Washington—Whitman	52	5	41	2	8	92	------	------	------	------
Montana—Judith Basin	40	33	25	2	9	91	------	------	------	------
North Dakota—Hettinger	57	36	2	5	10	72	6	------	------	12
North Dakota—Benson	70	15	8	7	8	87	1	------	------	4
South Dakota—Roberts	80	16	------	4	11	63	25	------	------	1
Nebraska—Filmore	82	15	------	3	9	52	37	------	------	2
Kansas—Sherman	65	33	------	2	5	47	47	------	------	1
Oklahoma—Garfield	72	25	------	3	4	78	18	------	------	------
Texas—Dallam	72	26	------	2	10	61	29	------	------	------
COTTON FARMS										
Texas—Lubbock and others	80	[1] 20	------	([1])	13	4	29	53	------	1
Texas—Bell and others	87	[1] 13	------	([1])	5	5	23	63	------	4
Texas—Smith	64	22	------	14	11	------	27	62	------	
Mississippi—Sunflower	79	[1] 21	------	([1])	------	------	9	91	------	------
Mississippi—Jones	49	[1] 51	------	([1])	6	------	37	51	------	6
South Carolina—Anderson	54	21	------	25	15	6	22	57	------	------
Alabama—Marshall	65	10	------	25	6	------	35	56	------	3
Georgia—Mitchell	50	17	------	33	8	9	50	21	1	[2] 11
TOBACCO AND OTHER TYPES OF FARMS										
Kentucky—Madison	42	46	------	12	12	41	35	------	12	------
Virginia—Charlotte	28	12	------	60	32	16	27	------	18	7
Tennessee—Greene	52	26	------	22	37	28	28	------	6	1
West Virginia—Lewis	8	80	------	12	76	------	18	------	------	6
Virginia—Northampton	47	2	------	51	7	------	------	------	------	[3] 93

[1] Classified as "pasture and other" or "pasture and woods."
[2] Largely peanuts and truck crops.
[3] Potato and truck-crop area. Potatoes, 78 percent; truck crops, 11 percent; other crops, 4 percent.

Corn Belt Meat Production and Intensive Cropping

To the south of the northern dairy region in the Central States lies the important meat-producing region of the United States. This region is characterized by deep fertile soils, level to rolling topography, and a moist warm climate during the growing season. It is well adapted to the intensive production of corn, which is fed to hogs and beef cattle. Unlike the northern dairy region, a very large percentage of the land is in crops; and of the cropland an exceptionally large proportion is in corn (table 1), while only a small proportion is in hay and pasture. Thus, for the six counties for which figures are given in the table, 57 to 81 percent of the farm land is in crops; and of the cropland, 48 to 57 percent is in corn. Small grains, largely oats and wheat, occupy 26 to 36 percent of the cropland, while hay is grown on only 7 to 20 percent.

This intensive system of cropping represents an adjustment to local factors. Perhaps no other major area in the United States could have withstood so well the heavy drain imposed upon the soil by the system of farming carried on in the Corn Belt; but, even so, after less than 100 years of intensive grain and livestock farming, evidence of severe soil and gully erosion is apparent in many sections. The fact that crop yields have remained relatively high in much of the area is due largely to the original high productivity of the soil, combined with the skill of agricultural technicians who have improved varieties and cultural practices, and in some cases advised the use of fertilizers.

Spillman (*378*) in 1906 pointed out the vast differences in natural fertility of soils as follows:

> Some [soils] do not produce well from the start unless special attention is given to making them productive; others produce large crops for a short time and then rapidly diminish in fertility; while others, known as strong soils, remain productive for many years without attention to their fertility. But even the strongest soils will wear out in time unless they are intelligently managed. Curiously enough, as the tide of migration went Westward in this country, the settlers found soils of increasing natural fertility, and in each new settlement the opinion prevailed that the soil was inexhaustible. But even the strong soils of the Western prairies have now been cropped with grain and abused by improper methods of tillage until they show signs of approaching exhaustion.

In the more than 30 years since Spillman's statement science has found numerous adjustments capable of rebuilding or maintaining soils. Only slowly, however, are these findings put into general use. Alfalfa, sweetclover, and other leguminous crops as additions to the farming system have increased in the Corn Belt States, while other cultivated and wild grasses have decreased. But in some sections little livestock is kept. Here the sales from the farm are principally corn, oats, and wheat. This system is followed generally on the stronger soils—soils that are deep, fertile, and when well drained very productive for many years after they are brought into cultivation. Even when most of the grain is fed to livestock and hay and pasture are included in the farming system, corn frequently follows corn in the rotation for 2 to 3 years.

After less than 100 years of farming some of the stronger soils are still being cropped heavily with corn and producing excellent yields; but on the fringes and in sections where the soils were less productive,

serious erosion and depletion of fertility is becoming more and more apparent. As a result, in some sections soil washing and decreasing yields have forced farmers to decrease the proportion of land devoted to corn and to start the process of soil rebuilding.

Such rebuilding is difficult at best. Not only are time and money required, but during the process farm returns are relatively, and often absolutely, low. Consequently, the rebuilding process becomes not only slow and costly, but practically impossible for the farmer who is heavily in debt, since cash sales must continue if he is to pay interest, taxes, and other necessary cash expenses. The farmer faced with this dilemma often continues his destructive system of farming and burdens himself and society with the unfortunate fruits of his soil misuse. Lower yields, lower production, and lower income result.

Exclusive Cash-Grain Production Decreases Yields

Not many years ago a rather general opinion prevailed among farmers that our better lands would produce cereal crops exclusively for an indefinite time without declining yields. Experience has proved this opinion to be wrong. Good harvests for several years while the soils were new and then a decline in yields has been the history of agricultural regions where farmers have followed an undiversified system of small-grain farming. Numerous examples can be found where farmers have been forced to adopt a more diversified type of agriculture because of declining yields and increasing weediness. Hunter (*172*) points out that wheat was produced quite successfully in the East for something like 40 years. During the latter part of that period the yields began to decline, and at the end of another 20 years they were so low that exclusive wheat growing became unprofitable. The Central States have each in turn repeated the history of the East. The soils of these States were productive in the beginning, and it required 40, 50, or 60 years for the single-crop system to reduce the yields materially.

In the Willamette Valley, Oreg., wheat was the principal crop for about 60 years. In the beginning large yields were obtained, but the soil soon became foul with wild oats and other weeds. The summer-fallow system was then adopted. The yields gradually declined on land that produced wheat continually, until as low an average as 10 to 12 bushels to the acre was reached. These low yields drove many to other types of farming. The Sacramento Valley, Calif., another excellent example, likewise produced wheat by the summer-fallow system with steadily declining yields.

The virgin soils of the Palouse country and the foothills of the Blue Mountains were once mellow and friable, with a desirable crumb structure, and produced excellent yields of wheat. After less than 60 years of farming principally to wheat, yields decreased substantially. The system of farming followed—summer fallowing and cereal crops—used up the organic matter in the soil faster than it was added. This caused the soil to lose its crumb structure and productivity. These examples of maladjustment, readjustment, and correction can be multiplied manyfold.

In much of the Great Plains region and in portions of the Northwest, wheat and to a limited extent other small grains occupy a very

large part of the cropland. On cash-grain farms in Washington, Montana, and North Dakota, as shown in table 1, 70 to 90 percent of the cropland, not including land in summer fallow, is used for the production of small grain. Hay is grown only in a limited way and makes up but 8 to 10 percent of the crop acreage. Farther south, cash-grain crops are still of major importance although one-sixth to one-half of the land is in corn and grain sorghums. In several areas where the farms are highly mechanized nearly the entire crop acreage is in wheat. In other areas considerable land is still in native range pastures.

In the Great Plains region many examples can be found of changes in farming systems from small grain alone because of decreasing wheat yields and encroachment of weeds. Large units of grazing land were subdivided into relatively small farms in which wheat is one of the principal sources of income. In this region drought is not uncommon, and in dry years not only are the small farm units incapable of producing a living for the family, but where a high percentage of the land is plowed for crops, whether intertilled or close growing, wind erosion destroys many acres that were originally in native range pastures and for many reasons suited only for such use.

Numerous studies relating to the Great Plains region point to the serious effects from drought and soil blowing as a result of the adoption of a system of farming in which cash grain plays too important a part.

Cotton Farming Depletes the Soil

The South is frequently referred to as a region of one-crop farming. This is true only in the sense that cotton, the major cash crop, normally occupies a very large part of the crop acreage. In addition to cotton, the South produces many other crops, such as corn, tobacco, peanuts, sweetpotatoes, small grains, rice, sugarcane, hay, pecans, and numerous fruit and vegetable crops.

The several crops are primarily clean-cultivated and usually found in combinations on individual farms that do not lend themselves well to systems of farming that prevent soil erosion and fertility depletion. Averages for the nine States [3] show that in 1929 nearly 75 percent of the cropland was used to produce cotton, corn, and grain sorghums, and only 7.5 percent was used for hay production. Typical cotton-producing farms have an even larger proportion of the cropland in corn and cotton, as indicated for eight counties in table 1.

Although there are large numbers of livestock in the cotton States this is not a commercial livestock region. Cropping systems in which so large a part of the land is planted to cultivated crops and in which livestock production plays an unimportant part are in themselves conducive to soil erosion and depletion of fertility. The mild climate and open winter season add to the difficulty of arresting soil washing and leaching where the land has been planted to a cultivated crop.

In general, farm experience has proved that the incorporation of large quantities of vegetable matter in the soil is a major factor in rebuilding and maintaining soil fertility in the South. Systems of farming in much of the South fail to take into account this well-known

[3] North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Arkansas, Texas, and Oklahoma.

principle of soil maintenance. To this end many crop rotations have been planned for southern agriculture, but their general adoption has been slow, principally because they have serious defects in adaptation to commercial agriculture.

Quite like early settlers in other sections of the country, pioneer farmers of the South did not readily recognize soil-fertility problems. The land was cleared of trees and for several years produced good crops of corn, cotton, and tobacco, and in some sections good crops of small grain. Land was abundant, and areas on which yields of these crops had fallen below the line of profitableness were turned out to grow up to broomsedge, then bushes, and finally to second-growth pines. In this way a few acres of the poorer land were abandoned each year and areas of new land cleared and used for crop production. Thus, on many of the lands of low or only moderate fertility, a long rotation was established. The time element in completing one cycle in such a rotation varied considerably, extending all the way from 20 to 50 years or more. On the better lands this type of rotation was considerably shorter. These so-called natural rotations have not entirely gone out of use in several sections of the South.

Opportunity exists in the South for the production of more grain and forage crops for home consumption, but numerous elements in the farm economy prohibit the extensive production of feed crops for sale or for commercial livestock production. The continued specialization in cotton production in many areas is due to the fact that cotton has a greater comparative advantage in such areas than has any other commercial enterprise or combination of enterprises, particularly on small farms. Only through an intensive system of farming with crops that have wide market possibilities can the operators of these small farms find sufficient employment on the home place.

It has been estimated that on the average 30 million acres of land devoted to the production of cotton will furnish about 255 million days of work per year in growing, harvesting, and hauling the crop to the gin. If the same acreage were put in corn it would require only 110 million days of labor, or less than one-half of the time required by cotton, and if seeded to oats or hay the total days of labor required to produce and harvest these crops would amount to from 45 to 50 million days, or an equivalent of one-sixth to one-fifth as much labor as if the land were devoted to cotton production. Furthermore, the return to labor for each hour spent on cotton is usually considerably greater than for each hour spent in growing the important feed crops or in livestock production.

In general, yields of feed crops and permanent pastures in the South are so low that relatively large acreages are required to produce any sizable volume of business in livestock farming. It has been estimated that on the basis of average yields and farm prices during the 10-year period 1923–32, an average of almost two to nine times as many acres of land were required to produce $100 worth of products in the case of dairying, beef cattle, and hogs as were required in the case of cotton. These averages are based upon conditions existing in the eight principal cotton States lying east of Oklahoma and Texas. In some areas within this vast region the adjustment is relatively easier, for conditions are more suitable to livestock production than

is indicated above, owing to higher yields of feed crops and pasture, and because the boll weevil limits the possibilities in cotton farming.

It may be concluded that much of the misuse of the soil in the South results from a maladjustment between the local resources and the systems of farming in which tilled cash and feed crops occupy a very large part of the acreage, and in which little vegetable material or animal manure is returned to the soil. A partial correction of the situation is feasible by the more general use of winter cover crops and the use of summer legumes for soil improvement. An adjustment through changing the system to one in which pasture and hay crops are of major importance as a means of commercial livestock production is difficult of accomplishment in many sections.

Depletion of Land Resources in Poor Farming Areas

In all sections of the United States the problem of adjusting the systems of farming to the local resources so that soil fertility will be maintained and the farm families enabled to make a living is similar in one or more respects to the problems discussed for the major type-of-farming regions. Soil misuse started on many lands when they were first cleared of timber; in commercial lumbering areas, like northern Michigan and northern Wisconsin, it began when the cut-over lands were divided into farming units and sold at speculative prices. Many poor lands put in cultivation were soon worn out. The difficulty of controlling erosion through the use of cover crops on steep lands that have been farmed is apparent in many sections.

On numerous hilly farms in the United States only a small part of the land is in tilled crops, but that part may be so steep that even when sound crop rotations are followed erosion and soil depletion are much more rapid than on deep, fertile, level soils even when intensively cultivated. It must not be assumed, therefore, that systems of farming in which hay or pasture occupies a large percentage of the land always achieve soil-erosion control. Neither can it be assumed that intensive cultivation of some of our deep fertile soils will cause erosion. A good adjustment in one case may be a serious maladjustment in another.

In the hilly sections of the East and extending southward and westward into the Ozark region are many farms with a large percentage of land in woods, permanent pasture, and hay. Many of these farms are so hilly that considerable erosion takes place even on the hay lands as well as on the small acreage devoted to tilled crops. In such sections a vital problem of the individual farmer is to arrest soil loss on the small acreage most suitable for cultivation and to produce better hay crops by reseeding the land more frequently. Another vital problem, if soil erosion is to be controlled on these hilly lands, is the maintenance of permanent pastures. Frequently it is difficult to obtain a good permanent stand of grass, and even when such a stand is obtained it is sometimes practically destroyed through overgrazing.

In this region, particularly in the mountain section, there are many farms of 40 to 160 acres that furnish their operators a mere subsistence income. Cash sales frequently average no more than a few hundred dollars per year over a period of years and often go as low as $100 or less.

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Nearly 20 years ago Arnold (*18*) estimated that the average receipts on about 100,000 mountain farms were about $100 per year. Obviously, very little was sold from many of these farms, especially the smaller ones. The average land distribution of these typical mountain farms is shown in table 2.

Table 2.—*Distribution of land by crop or other use on three typical small southern mountain farms*

Land use	Example No. 1	Example No. 2	Example No. 3
	Acres	*Acres*	*Acres*
Woods	48	46	36
Idle land resting or partly in pasture	20	25	6
Other pasture (permanent)	------	------	15
Corn	12	15	6
Hay and other forage	2	3	14
Oats	1	2	4
Wheat	------	2	2
Rye	------	1	------
Sorghum	0.25	1	------
Buckwheat	------	------	2
House, barn, garden, potatoes, orchard, etc.	1.75	1.5	1.5
Total	85.0	96.5	86.5

As may be seen from the relatively large percentage of the land that is idle or resting, the farming of such lands has resulted in soil misuse. Even by taking from the farm all that can be gotten each year, an exceptionally low standard of living is obtained by the farmer and his family.

Size of Farm Related to Soil Misuse

Reference has already been made to the fact that within a given type of farming, farms vary in size and productivity, and that in numerous instances they are so small that the establishment of a system of farming that will conserve soil and produce a desirable family income is practically impossible. The idea of a small farm and economic independence is unfortunately too often a myth except under very favorable circumstances.

Small areas become farm units for several reasons. Often the prospective farm operator can afford only a small place. Promotion and real estate subdivision have lured many people to purchase small holdings that can with difficulty be made to produce a living. Sometimes a man inherits a unit that is too small for his family needs.

Of the 6¼ million farms reported in the Census of Agriculture of 1930, approximately 6 million were classified by gross value of product and by size of farm (table 3). Of these farms nearly 37 percent were less than 50 acres in area, and almost half of these produced products with a gross value of less than $1,000 annually. The net value of the products to the farmer was of course considerably less than $1,000.

Although area alone does not always determine the size of the business, area and income-producing ability may be said to go together fairly well, judging by the figures (table 3). Exceptions are to be noted for some types of farms (table 4). Intensive types, such as poultry, fruit, and truck-crop farms, produce relatively good incomes on relatively small acreages. But farms of these types are restricted in number and not suited to many sections of the country. On the other hand, small farms of the more extensive types are relatively low income producers.

Table 3.—*Size of farm and gross income*[1]

Size of farms			Gross value of products		
Area (acres)	Farms	Percentage of total farms	Per farm (dollars)	Farms	Percentage of total farms
	Number	*Percent*		*Number*	*Percent*
Less than 3	38,263	0.6	Under 250	397,517	6.6
3-9	283,538	4.7	250-399	518,032	8.6
10-19	515,017	8.6	400-599	766,118	12.8
20-49	1,359,851	22.7	600-999	1,245,684	20.8
50-99	1,321,558	22.0	1,000-1,499	937,910	15.6
100-174	1,300,368	21.7	1,500-2,499	981,163	16.4
175-259	508,240	8.5	2,500-3,999	628,006	10.5
260-499	439,839	7.3	4,000-5,999	291,112	4.8
500-999	154,747	2.6	6,000-9,999	147,753	2.5
1,000-4,999	69,385	1.1	10,000-19,999	61,606	1.0
5,000-9,999	5,130	.1	20,000 and more	24,981	.4
10,000 and more	3,946	.1			
Total[2]	5,999,882	100.0	Total	5,999,882	100.0

[1] U. S. Bureau of the Census, 1930.
[2] Does not include 288,726 farms that were not classified as to income.

Table 4.—*Characteristics of farms by types* [1]

Type of farm	Farms	Proportion of all types	Average size of farm	Gross value of products per farm	Farms with less than 50 acres	Farms with less than $1,000 gross income
	Number	*Percent*	*Acres*	*Dollars*	*Percent*	*Percent*
Cotton	1,640,025	27.3	72	1,035	56	65
General	1,044,266	17.4	138	1,479	20	42
Dairy	604,837	10.1	139	2,764	14	15
Self-sufficing	498,019	8.3	70	425	50	98
Animal specialty	479,042	8.0	230	3,634	6	12
Cash grain	454,726	7.6	352	2,943	5	18
Crop specialty	431,379	7.2	109	1,934	41	43
Abnormal	384,092	6.4	72	1,073	67	92
Poultry	166,517	2.8	62	1,988	58	40
Fruit	141,418	2.3	71	3,354	66	35
Truck	84,561	1.4	60	2,880	65	35
Stock ranch	71,000	1.2	2,912	7,174	8	19
All types[2]	5,999,882	100.0	157	1,835		

[1] U. S. Bureau of the Census, 1930.
[2] Does not include 288,726 unclassified farms.

Obviously, destructive cropping systems and practices may be in use on large farms as well as on small farms. But small farms of any type, especially when heavily planted to cash and soil-depleting crops, are less readily adjusted to soil-conserving systems and practices than are the larger farms. The more effective and economical operation possible on the large farm is impossible on the smaller. The labor is inadequately used, or the power is wasted, or the equipment is expensive in proportion to the area handled and the total production, or there is some other maladjustment resulting in inefficiency and low income.

Any proposed solution of the problem must be founded on an understanding of the agricultural possibilities of the various type-of-farming

areas. Within each type of farming are to be found certain optimum physical and economic adjustments of crops to each other and of crops to livestock, all based upon optimum interrelations of soil, slope, climate, labor, power, use of equipment, and managerial ability. Deviations from these optimum relations are certain to lessen opportunities for income, economical operation, and soil conservation.

In an attempt to increase his income, the small-farm operator is forced to overwork the soil in an effort to make a living. The injury to the soil is not apparent at first, and when it becomes apparent, the damage is already done. Retreat is impossible. The development of farming systems that will conserve soil and produce at least a modest living without overworking the land must be based first on adequate soil and water resources for the individual farm.

FARM TENANCY

One of the outstanding agricultural developments of the past half century has been a continual increase in the number of farm tenants, and simultaneously the development of a class of absentee or nonoperating farm owners. Throughout most of the history of this Nation, the great majority of our farmers have owned the land they operated. In most communities, the individual farm was owned, managed, and cultivated by the same man.[4] Of course, there was some tenancy and absentee ownership as early as the Colonial period. However, it was not until the latter part of the last century that the development of farm tenancy began to become significant. When the good farm land in the public domain began to disappear and agriculture became more highly commercialized, absentee ownership and tenancy grew.

Table 5.—*Number and proportion of tenant farmers in the United States*

Year	All farmers	Tenant farmers		Year	All farmers	Tenant farmers	
		Number	Percent			Number	Percent
1880	4, 008, 907	1, 024, 601	25. 6	1920	6, 448, 343	2, 454, 804	38. 1
1890	4, 564, 641	1, 294, 913	28. 4	1930	6, 288, 648	2, 664, 365	42. 4
1900	5, 737, 372	2, 024, 964	35. 3	1935	6, 812, 350	2, 865, 155	42. 1
1910	6, 361, 502	2, 354, 676	37. 0				

The number of farm tenants increased from 1,024,601 in 1880 to 2,865,155 in 1935 (table 5). This was a gain of 180 percent, while the number of farms not operated by tenants increased only 32 percent. There was not a decade between 1880 and 1930 in which the number of tenant farms did not increase faster than that of owner-operated farms. The increase of almost 2,000,000 tenant farmers that took place between 1880 and 1935 was not brought about by an even and gradual growth during all of this period nor by continuous increases in all sections of the country. During the two decades from 1880 to 1900 there was a general increase in both the number and proportion

[4] The only significant exception to this general situation was the Southern plantation system. Before the Civil War most Southern plantations were managed by their owners, but they were cultivated by slaves—legal chattels of their owners.

of farm tenants in practically all areas. However, a large part of the increase in tenancy that has occurred in the United States since the beginning of this century has been in regions of specialized cash-crop production.

With the expansion of cotton, corn, wheat, and tobacco production, there has been a concomitant expansion in tenant farming. For instance, the percentage of tenancy in the areas of the country that are predominantly wheat areas at the present time jumped from 23 in 1910 to 42 in 1935 (table 6). The approximate gain in the total number of farms was 38,000, but the increase in tenant-operated farms was about 76,000. In the corn region the total number of farms declined, but tenant-operated farms increased by over 57,000, and the percentage of tenancy rose from 37 to 45. Obviously, tenancy was displacing owner-operatorship in the wheat and corn regions between 1910 and 1935. In the cotton region the increase in number of tenants was large, though the change in percentage of tenancy was not great. In contrast to the unusual increases in tenancy in the cotton, corn, wheat, tobacco, rice, and sugarcane regions, there were only moderate gains in the general-farming and dairy regions. In the general-farming areas, for instance, the percentage of tenancy was 27.2 in 1910 and had increased to only 29.5 in 1935. The increase in the dairying areas was about the same.

Table 6.—*Number of all farms and number and percentage of farms operated by tenants in the principal types of farming regions in stated years*[1]

Type-of-farming region	All farms				Tenant farms							
	1910	1920	1930	1935	1910		1920		1930		1935	
	Thousands	*Thousands*	*Thousands*	*Thousands*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*
Cotton	1,662	1,715	1,785	1,824	1,011	60.1	1,040	60.6	1,200	67.2	1,187	65.0
Corn	970	940	907	928	359	37.1	376	40.0	388	42.8	417	44.9
Wheat	312	332	334	350	72	23.0	100	30.2	130	39.0	147	42.1
Tobacco	470	517	489	512	203	43.4	236	45.8	249	50.8	252	49.2
Rice	23	25	31	34	11	44.9	12	49.5	19	60.1	20	58.7
Sugarcane	10	10	9	12	4	41.0	4	44.8	4	48.2	5	45.5
Dairying	764	741	663	753	131	17.1	124	16.7	108	16.3	140	18.6
General farming	730	697	645	746	199	27.2	180	25.8	170	26.4	220	29.5
City areas	266	221	257	275	68	22.4	53	23.8	64	25.1	67	24.2
All other	1,155	1,250	1,169	1,378	297	25.7	330	26.4	332	28.4	410	29.7
Total	6,362	6,448	6,289	6,812	2,355	37.0	2,455	38.1	2,664	42.4	2,865	42.1

[1] Compiled and calculated from statistics of numbers of farms by counties as published by the Bureau of the Census. Only those farms comprised wholly of land not owned by the operator are counted as tenant farms. The regions are those outlined and described in Regional Problems in Agricultural Adjustment (*423*). Since the outlining of the regions was done on the basis of statistics for a recent census, types of farming may have been somewhat different in earlier years. Nevertheless, the data show the past growth of tenancy in what is now the designated type of farming region.

In addition to the 2,865,155 farm tenants enumerated by the census of 1935, there were 688,867 farmers who owned part of the land they operated and rented part of it. The total number of farmers who were renting all or a part of their land represented 52 percent of all farmers. When the farm land rented by part owners is added to that rented by tenants, it is seen that 45 percent of all land in farms was operated under lease in 1935. About half of the land in farms was

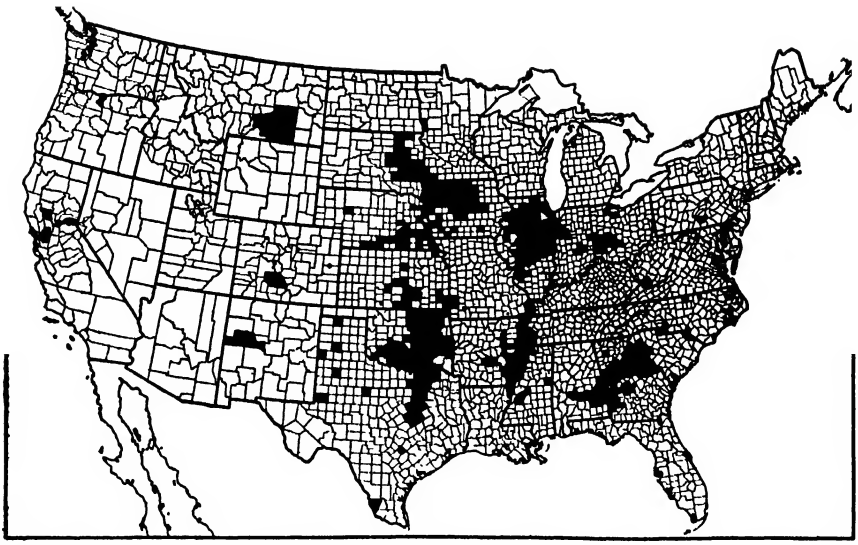

Figure 2. - Counties in which at least half the land in farms was under lease to the operator, 1910.

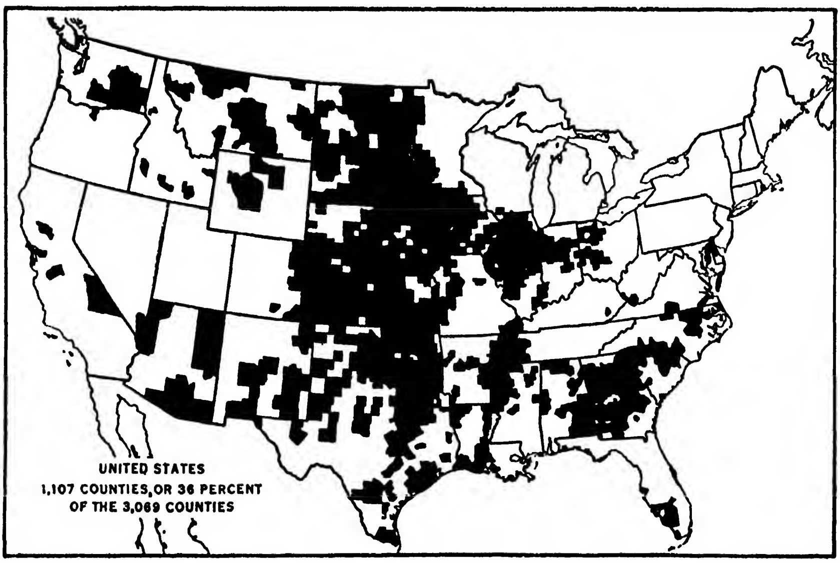

Figure 3.—Counties in which at least half the land in farms was under lease to the operator, 1935.

under lease in such important agricultural States as Illinois, Iowa, North Dakota, South Dakota, Nebraska, Kansas, South Carolina, Georgia, Alabama, and Oklahoma. Between 1910 and 1935 the number of counties in which at least half the land in farms was under lease to the operator increased from 14 to 36 percent of all counties.

In 1935, these counties included most of the alluvial and prairie areas of the country, and also most of the Piedmont and upper Coastal Plain of the Southeastern States (figs. 2 and 3).

Tenancy and Soil Conservation

From the standpoint of soil conservation the development of farm tenancy and absentee ownership is of significance primarily through its effects upon land-use practices. In the case of tenancy at least two parties are looking to the land as a source of income. If all parties having to depend for their income on agriculture had the right attitude toward the land, that is, a long-time interest in the maintenance of the producing power of the land, tenancy would not be associated with eroding soil and neglected structures. As it is, however, tenancy too often causes the tenant, and sometimes the landowner, to be interested only in the highest possible immediate income from the land, regardless of its future productivity.

The nature of customary farm-rental agreements has much to do with the present general lack of interest shown by landlords and tenants in the maintenance and improvement of farms. These customary agreements were developed during a period when the soil was exploited as a matter of course. They therefore naturally reflect a policy of ignoring, in large degree, the growing problem of soil maintenance and restoration.

The relative inflexibility of customary practice in renting farms has been a restraining influence to many who should now be taking steps to adjust their leasing arrangements in ways that would stimulate the conservation and improvement of farms. The necessity for taking such steps is naturally greatest in the case of farms composed of lands that have been badly abused in the past or are naturally highly susceptible to deterioration. One way of enlisting the cooperation of a tenant in the improvement of a farm is to assure to him reasonable rights of occupancy without increases in rent. However, concessions from the customary method of renting may also be necessary, particularly if a relatively desirable tenant is to be found and held on a farm that is rather below average in desirability.

For the more desirable farms, landlords usually have a good choice of tenants and can do much, even under customary rental practice, to make certain their farms will be well taken care of by taking the precaution to select good tenants and making it worth while for them to look after the farms they work.

Many landlords are so fixed financially that they feel they must get every possible dollar from their farms each year, regardless of future production or value. These landlords commonly select their tenants, therefore, on the basis of the prospect they offer of raising the largest possible crop in the year immediately contracted for. Furthermore, they naturally endeavor to throw upon their tenants as much as possible of the costs of erosion control.

Essentially the same policy is frequently followed by landlords with a good financial standing—men who could afford to make concessions in the rent or expend considerable sums in the furtherance of farm improvement. Sometimes these landlords follow this policy because they have not given the problem of maintaining their farms proper

consideration. Others remain skeptical of the advantage they might reasonably expect to reap after making sacrifices to improve their places. This is unfortunate. Tenants have been encouraged too long and too generally to exploit farms, and have not been held responsible for maintaining them in as good condition as when they were taken over.

Tenants and tenancy have long been generally held responsible for much of the divergence between actual practices in soil use and practices that would further the long-time national interest.[5] There is much statistical evidence to confirm such an opinion.

In 1925 only 38.6 percent of the farmers were tenants, yet on the farms they operated there was harvested, in 1924, over two-thirds (67.6 percent) of the cotton acreage, 49.4 percent of the tobacco acreage, 47.3 percent of the corn for grain, 41.6 percent of the oats for grain, 38.1 percent of the wheat, 35.5 percent of the flaxseed, and 43.8 percent of the beets for sugar. But of such a crop as corn cut for silage they had only 24.6 percent of the total. That year they had 40.6 percent of the cropland harvested; 10 years later, in 1934, they had 42.1 percent.[6] Presumably, therefore, in 1934 and in more recent years they had even greater percentages of the acreages in soil-depleting crops, such as cotton, tobacco, and corn for grain, than they had in 1924.

Statistics of farms by type and tenure afford further confirmation of the tendency for farming under lease to be of a soil-depleting type. In 1930 tenants operated 73 percent of the cotton and 51 percent of the cash-grain farms. Of the crop-specialty farms, including farms devoted to such crops as tobacco and sugar beets, tenants had 47 percent. At the same time tenants operated only 30 percent of the animal-specialty farms, only 21 percent of the dairy farms, and only 27 percent of the self-sufficing farms.

In 1900 tenants had 68 percent of the farms from which cotton provided the principal source of income in 1899. On the same basis they had 48 percent of the tobacco farms in 1900, 39 percent of the hay and grain farms, 23 percent of the dairy farms, and 20 percent of the livestock farms.

A special tabulation of 1935 farm census data in 27 selected local areas distributed among the cotton, tobacco, wheat, and corn regions indicates that tenants have a higher proportion of the land in crops than owners, and conversely a lower percentage in pasture.[7]

That overcropping and specialization in the production of soil-depleting crops is an important characteristic of tenant farming is indicated by data obtained within local communities as well as by census data for the entire country. A farm survey in southwestern Iowa revealed that on rented farms 66 percent of the cropland was in soil-depleting and erosive crops (corn and soybeans), as compared to 56 percent on owner-operated farms, and only 15 percent in soil-

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[5] A Farmers' Bulletin issued in 1907 (62) begins: "It is seldom that a tenant farmer pays much attention to increasing soil fertility. Run-down and worn-out farms that have been worked on shares in all the old settled sections prove the truth of this statement."

[6] In the South the tenant farms contained 51.3 percent of the cropland harvested in 1934, 32.3 percent of the other land in farms. In the other 32 States, farms operated by tenants contained 37.2 percent of the cropland harvested and 25.5 percent of the other land in farms.

[7] In 1934, of the land in all full-owner farms 28 percent was cropland harvested and 11.1 percent in plowable pasture; of the land in tenant farms 36.9 percent was cropland harvested and 8.5 percent in plowable pasture.

conserving grasses and legumes, as compared to 21 percent on owner-operated farms.[8]

In many areas in the Middle West the relative corn acreage on rented farms is 20 to 25 percent greater and the degree of current erosion substantially higher than on owner-operated farms (*342*).

Specialized crop farming, especially of the type carried on in these regions, is much more depletive of soil fertility than is livestock farming. Yet American tenants appear to specialize in crop production on practically all sizes and types of farms to a much greater extent than the owner operators in the same communities. For instance, in 12 selected cotton areas full owners had 40.6 percent of their farm land in crops in 1934, whereas croppers had 64.3 percent, and other tenants 56.7 percent. Substantial differences of this nature existed on practically all sizes of farms. In the wheat region, full owners had 48.5 percent of their farms in crops, compared with 55 percent on tenant farms. In the corn region, the proportions were 58.5 percent on full-owner farms and 65.8 percent on tenant farms. The same general situation was found to be true in three tobacco areas.[9] Although the size of the farm was related to the specialization in crop farming in all four areas, the tenant farms planted more of their land to crops than did owners on practically all sizes of farms (table 7).

The question as to why the tenant depletes his soil more rapidly than the owner operator naturally arises. Why does the tenant keep few livestock, have little land in pasture, and encourage erosion by growing a high proportion of intertilled crops? Why doesn't he keep the farm buildings and fences in repair, and show the same interest in the farm he rents as he would in a farm he might own? The answers to these questions are to be found largely in the nature of the lease contract, and more fundamentally in the traditional attitude of people toward the land.

Farms are ordinarily rented for a year at a time without assurance of renewal; and renewals, if granted at all, are commonly withheld until harvest time, or even until a few weeks before the expiration of the lease. With such short-time arrangements, a tenant has little inducement to apply his managerial talent, his labor, and his capital to anything except short-time exploitative enterprises in which soil maintenance and improvement work have no part. All his assets must be in a liquid or movable form by the end of his rental year. He is here today and may be gone tomorrow, not because he wants to but because that is the way our farm tenancy system works. The uncertainties of his occupancy and the requirements of his lease dictate quite definitely what crops he can grow and what livestock he can keep to advantage. Hence he is largely a producer of cash crops such as cotton, tobacco, corn, and small grain, and he is not concerned that these crops are hard on most soils.

Annual cash crops lend themselves to the needs of tenant farmers who have uncertain occupancies, for these crops do not have to be

[8] SCHICKELE, R., and HIMMEL, J. P. PROBLEMS OF LAND TENURE IN RELATION TO LAND-USE ADJUSTMENTS. U. S. Resettlement Administration, Land-Use Planning Pub. 9, 47 pp. 1936. [Mimeographed.]

[9] The percentage of farm land in crops is not wholly satisfactory as a criterion of soil exploitation. There is a tendency for the proportion of tenant farms to be higher on good land than on poor land within a given community. Since good land is ordinarily better suited and more generally used for cropping than poor land, these data may slightly overstate the exploitative nature of tenant farming.

fed on the farm to realize on their value. Tenants who feed crops to productive livestock at all are most commonly interested in hogs, which have a relatively short cycle of growth.

Table 7.—*Land utilization on full-owner and tenant-operated farms compared, size of farm considered, four types of farming regions, 1935* [1]

Type-of-farming region and size of farm (acres)	Farms operated by—			Farm land in crops			Farm land in pasture		
	Full owners	Tenants		Full owners	Tenants		Full owners	Tenants	
		Croppers	Others		Croppers	Others		Croppers	Others
Cotton:	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
All sizes	7,623	5,611	8,781	40.6	64.3	56.7	33.1	15.1	22.6
Under 3	28	1	16	39.0	-------	32.0	7.3	-------	8.0
3-29	853	2,426	1,763	58.0	88.1	80.8	21.5	3.0	7.7
30-49	1,451	1,597	1,842	53.8	75.9	65.9	20.5	7.9	13.3
50-109	2,838	1,203	2,827	45.8	63.2	53.2	27.0	15.0	22.0
110-209	1,652	301	1,646	43.2	47.0	56.7	29.2	23.7	21.8
210-269	278	33	241	38.4	45.9	58.4	32.1	20.9	23.6
270-369	290	32	286	47.7	45.9	65.5	29.7	27.2	20.2
370 and over	233	18	160	23.6	20.1	41.0	51.5	48.6	38.1
Tobacco:									
All sizes	2,032	1,753	1,331	32.6	46.1	41.6	45.8	15.2	36.5
Under 3	1	34	7	-------	100.0	-------	-------	0	-------
3-29	573	972	533	33.1	79.1	70.0	41.9	1.9	16.9
30-49	285	324	194	34.3	53.4	54.7	35.2	4.7	18.9
50-109	553	298	245	29.8	38.0	38.4	42.7	8.5	31.9
110-209	322	86	191	30.4	27.6	35.8	47.3	22.2	41.5
210-269	116	20	63	33.4	26.3	37.2	47.1	44.6	43.3
270-369	85	12	51	36.2	28.5	36.4	46.7	50.2	40.7
370 and over	97	7	47	34.2	-------	44.7	48.7	-------	38.6
Wheat:									
All sizes	1,221	-------	1,980	48.5	-------	55.0	37.8	-------	31.5
Under 3	4	-------	2	-------	-------	-------	-------	-------	-------
3-29	150	-------	108	44.3	-------	45.1	31.0	-------	34.4
30-49	56	-------	64	40.8	-------	49.7	46.7	-------	34.2
50-109	109	-------	181	45.2	-------	58.4	42.4	-------	28.1
110-209	318	-------	592	57.4	-------	59.5	27.2	-------	26.6
210-269	51	-------	134	50.8	-------	58.4	37.6	-------	27.2
270-369	227	-------	391	56.3	-------	60.7	29.3	-------	24.6
370 and over	309	-------	508	43.8	-------	51.1	43.1	-------	36.2
Corn:									
All sizes	5,427	-------	7,352	58.5	-------	65.8	32.3	-------	24.6
Under 3	21	-------	5	35.7	-------	-------	3.6	-------	-------
3-29	950	-------	451	28.7	-------	39.8	51.8	-------	40.6
30-49	390	-------	109	43.6	-------	59.3	44.1	-------	30.5
50-109	1,406	-------	1,513	57.4	-------	64.9	32.8	-------	25.6
110-209	1,890	-------	3,559	60.7	-------	67.0	30.6	-------	23.4
210-269	363	-------	813	59.3	-------	66.7	31.8	-------	24.0
270-369	277	-------	633	59.7	-------	65.6	31.5	-------	24.6
370 and over	130	-------	179	56.9	-------	60.1	34.5	-------	31.3

[1] These data are from a series of special tabulations made by the Bureau of the Census from the 1935 farm census schedules for the Land Use Planning Section, Land Utilization Division, Resettlement Administration. In each region small homogeneous areas were selected for which all farm census schedules were tabulated. The number of such areas in each region were as follows: Cotton 12, tobacco 3, wheat 4, and corn 8. In instances where there are less than 10 farms in a given size and tenure group the data on crop and pasture land are omitted from the table.

The initiative for the making of permanent or semipermanent seedings cannot be expected to come from tenants with short leases and uncertain occupancies. Nor is their cooperation encouraged in such work as may be desirable in the control of weeds, the application of phosphates and lime, tiling, fencing, maintenance and improvement of buildings, or even keeping up the outward appearance of the farmstead.

It is useless to argue that tenants are usually told they can expect renewals of their year-to-year leases so long as they satisfy their landlords. Such informal and unbinding assurances are of little value to tenants. All too often they know from observation, if not from bitter experience, that if they improve their places they may not get a renewal at all, or only at a higher rental, because others in search of farms may decide to buy at the offered price [10] or bid up the rent in consideration of the value of the improvements made. The tenant who makes improvements is thus deprived of the fruits of his labor and investment without compensation.

A large majority of tenant farms are rented on a crop-share basis. In 1930, 82 percent of all tenant farms in the United States were rented on shares, most of them under crop-share arrangements. Crop-share leases are particularly dominant in the high tenancy areas of the Middle West and the South (*421*). They naturally encourage the production of cash crops and discourage the production of crops that cannot be readily marketed but must be converted into livestock products on the farm. Hence wherever a relatively large acreage in cotton, tobacco, or grains is in conflict with proper soil conservation, this form of tenancy constitutes an important obstacle to the adoption of soil-conserving practices. This holds true for large areas throughout the Corn, Wheat, Cotton, and Tobacco Belts.

In the Middle West particularly, the crop-share lease obstructs an increase in soil-conserving grasses and legumes. Rent for pasture land on farms rented under crop-share leases must be paid in cash, and landlords usually charge a cash rent for hay land also, as hay is not a cash crop in most areas. Since the landlord's share in the cash crops is largely determined by custom, the bargaining between individual crop-share landlords and tenants is focused largely upon the determination of the cash rent per acre of grassland. The strong bargaining position the landlords have held in recent years, therefore, has resulted in cash-rental rates for grassland on crop-share farms commonly higher than the true worth of such grasslands to most tenants. This situation, of course, induces tenants to keep the acreage in soil-conserving grasses and legumes at a minimum. Landlords, too, receiving the bulk of their rent in the form of their share in cash crops, are primarily interested in having a relatively large acreage in such crops. Many fail to realize that an unreasonably high cash rent on grassland under a crop-share lease is often paid out of the landlord's own asset, the land. Under either the crop-share or the share-cash method of renting farms, the share of feedable crops going to the landlord usually leaves the farm and thus deprives the soil on which it was grown of the manure that might otherwise be returned. Tenants commonly feed some if not all of their share of the feedable crops other than wheat, and many tenants, with no more encouragement than permission to buy at a fair price, take over and feed the feedable crops of the landlord's share.

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[10] A recent study in Minnesota [11] reveals that the major portion of the rented land is for sale. More than two-thirds of the private landlords indicate that their farms are for sale, and this holds true for most corporate landlords.

[11] POND, GEORGE A. FARM TENURE IN MINNESOTA. Minn. Univ. Farm Business Notes 174, 3 pp., illus. 1937. [Mimeographed.]

On farms rented for cash the pressure toward land-use practices that deplete the soil is not usually so serious as on share-rented farms. Nevertheless, problems of an analogous nature arise. There is evidence that the cash rent usually charged for below-average farms is relatively higher than the rent for above-average farms. This means that the tenant on poor land carries a relatively greater rent burden than the tenant on good land, which results in a greater economic pressure upon the land that can least stand it. In conjunction with insecurity of tenure and lack of compensation for improvements, this must almost certainly result in practices that exploit rather than conserve the soil.

An increasing proportion of those who farm as owners are finding it necessary or desirable to rent additional acreage. Twelve percent of all who farmed as owners did this in 1900, and 18 percent in 1930 and in 1935. The acreage thus rented by owner farmers increased from 62 million in 1900 to 134 million in 1935. In the latter year this represented 28.5 percent of the total acreage under lease.

The natural interest of owner farmers in building up the fertility of the land they own affords reason for believing that the practices of these farmers on land they rent may be even more injurious than the practices of tenants who rent all of the land they farm. The latter do not have the same incentive to favor part of their land at the expense of the rest of it.

The nature of the lease contract is not, of course, the sole motivating force behind the exploitative farming practices followed on most tenant-operated farms. Factors largely of a personal nature are of importance. Tenant farmers as a group are younger than owner operators, not usually as experienced, and more often lacking in foresight and responsibility, and usually more anxious to accumulate capital rapidly, through cash crops, to buy a farm of their own. Since most persons who have become farm owners have had to accumulate all or a part of the funds with which to purchase a farm, it is probable that the tenant group includes a higher proportion of incompetent farmers than does the owner group.

Upwards of 700,000 of the tenant farms of the South are worked by croppers, over half of whom are colored. Shiftlessness and thriftlessness are major reasons why so many tenants in this part of the country are so poor as not to possess what little capital or credit it would take to provide the animals with which to work the land they farm. It should be kept in mind, however, that the tenure arrangements afford little incentive to the cropper to develop thrift and responsibility. Croppers seldom take the initiative in matters of soil improvement. Such is the rate of soil depletion where the farming is done with cropper labor that a few farm landlords attempt to offset it by growing improvement crops on part of their acreage with hired labor, alternating the fields allotted to croppers with fields for such use.

With the increasing industrialization of the South, increasing opportunities are afforded those landlords who are enterprising. Landowners who partake in these opportunities naturally concern themselves rather less with what happens to their land than they would otherwise, and so an absentee-owner attitude tends to develop

in a section where it so commonly takes the best of management to maintain the land.

Notwithstanding the influence of personal factors such as those mentioned, it is very probable that the terms and conditions of leasing are of greatest importance in motivating exploitative practices on rented farms. To a large extent these leasing arrangements are outgrowths of customary practices which were founded upon the pioneer American attitudes toward land. Traditionally, Americans have looked upon land as an instrument for quick profit making, through immediate returns from farming as well as from sale of the land at high prices. Landlords on their part have not desired to have their holdings tied up under a long-term lease because a favorable opportunity to sell the farm might arise at any time. Not infrequently tenants have looked with disfavor upon long-term leases because they wanted to be free to rent a better farm or buy one of their own. Moreover, ordinarily the landlord does not want to take the risk of establishing a lease that might force him to keep an unsatisfactory tenant for a long period; nor does the tenant want to be bound to the farm of an undesirable landlord. Leases have developed in such a way as to leave landlords free to sell the farm, tenants free to move, and both free to exploit the soil. Neither landlord nor tenant has desired to accept any great responsibility toward the soil, each taking only a transitory interest in its use in the quest for quick gains.

As men and women who have the future of the Nation at heart appreciate how seriously the possibilities of that future may be lessened by a continuance of present practices on tenant farms, it is to be expected that a demand will be voiced for better practice in leasing farms. It is too much to expect that voluntary, scattered efforts to improve leasing practices will suffice even after long-continued educational work on the subject. It is to be hoped that proper legislative measures may be enacted before the fertility of the land is too badly depleted. As increasing proportions of our agricultural lands become tenant-operated, the need for more adequate tenures increases.

IN THE FIELD ***of agricultural finance, mortgages and taxes are the two most prominent elements. Both are necessary, and they are here to stay. But need they be so arranged that they lead to undue hardship and therefore to soil misuse? Or is it possible to revise both mortgage and taxation methods so that they encourage better use of the land? These questions are raised by this article, which attempts to show some of the shortcomings of current methods.***

The Causes: Imperfections in Agricultural Finance

By David L. Wickens, R. Clifford Hall, *and* Donald Jackson [1]

THE RELATION OF THE FARM MORTGAGE TO SOIL DEPLETION AND TENANCY

A MORTGAGE may be as injurious to a farm as erosion or a poor cropping system. Although credit is commonly employed to enable farmers to buy their farms, a loan may nevertheless become the cause of destroying soil fertility and ultimately of losing ownership of a farm. It has often been pointed out that certain tenant arrangements result in overcropping and depletion of the soil, but it is not always recognized that this same condition may be caused indirectly by the terms of a mortgage on a farm operated by its owner. Many farmers in the United States operating their own farms have had this experience. The necessity of meeting payments on a mortgage that is unduly burdensome has caused many farmers to specialize in crops that reduce soil fertility, to neglect the restoration of plant food, and to fail to plant crops that prevent erosion. At the same time the farmhouse and the other farm buildings as well as the soil usually deteriorate.

The terms and conditions of American farm-mortgage financing that have given rise to some of these difficulties and are now traditional, came into being for the most part during a period when the soil of the Nation's farms was new and when continued fertility was apparently assured for a long time. The preservation of soil fertility was not then recognized as a problem. Consequently, it did not

[1] The section headed The Relation of the Farm Mortgage to Soil Depletion and Tenancy is by David L. Wickens, Eco[illegible]
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become the general practice to make any special provision for maintaining soil fertility in any arrangement involving the purchase or sale of land or in the extension of credit secured by land, or to provide for any supervision or inspection of farm practices. Farm-mortgage contracts were mainly concerned with formal provisions regarding the credit extended, the description of the property and enumeration of more or less standard terms for the loan, including the interest rate, and procedure to be followed in event of default. During all the years of expanding agricultural activity no special provisions were made in the loan instrument to encourage soil conservation, to relieve the borrower from the necessity of robbing the soil to make loan payments in price-depression years, or to foster farm ownership by the operator. Any provisions for care of the property were largely formalities.

The effect of declining fertility as related to the problem of mortgage financing and the purchase of farms was obscured during the long period from the 1890's to 1920 by the upward trend of farm prices and land values. Following the disappearance of the frontier and its free farms in the nineties, a general rise in the price of farm commodities occurred, and, stimulated by the war, farm land values quadrupled from 1900 to 1920. The farm-mortgage debt also rose in volume, but increasing debt during that period was not a serious problem for farmers. The added burden of expenses and debt payments was readily met out of increased farm returns as prices rose. Credit was ample for the refunding of old loans, including delinquent payments, into new and larger mortgages. The extent of this debt expansion is indicated by the fact that the value of the farm land in the United States rose 100 percent during the period 1910–20, whereas the amount of farm-mortgage debt increased 135 percent. The number of farms mortgaged, however, increased only slightly, from 33 percent in 1910 to 37 percent in 1920.

Those forces which tended toward expansion of both production and debt were especially active in the Middle West and in the semiarid lands, where under the favorable conditions of the times a large proportion of the farmers had recently acquired land, chiefly through mortgage credit. The census of 1920 showed that from 60 to 70 percent of the farms in most counties of this area were mortgaged. In Montana and North Dakota and the States extending southward a greater percentage of owner-operated farms were mortgaged than in any other section of the country. Before the end of the period rising land prices had come to be taken for granted and larger mortgages assumed in purchasing farms stirred no fear of risk for farm practice or farm ownership.

It was not until the collapse of farm prices in 1920 and the long decline in farm-land values during the following 13 years that the shortcomings of the prevailing finance methods became generally evident. The many tragic experiences of these years brought out clearly the dangers from high prices and excessive loans, and the peril concealed in mortgage terms and conditions not adapted to agriculture, not only for the gross damage possible to the soil but also by threatening the very basis of the farm family's efforts by depriving it of the farm it sought to own.

Mortgage Terms and Conditions

The vital significance of the terms and conditions of mortgage finance is of universal importance in the United States because so many American farms are mortgaged. In 1920, for example, 37 out of 100 farms occupied by their owners were mortgaged, and in 1935, 42 percent were mortgaged. The proportion of rented farms encumbered has been nearly as large. Most farms are bought on credit; few are paid for outright in cash. Whether a farm is located in an area where land prices are low or high, the cost is usually several thousand dollars. Mortgage financing for farm purchase is largely a device for postponing payment of the cost of the farm and so making possible the necessary saving after it is purchased. As a rule a long period is required to accumulate enough money to pay for a farm completely, and a large proportion of American farmers never succeed in doing so. There are always difficulties in saving the required amount of money from farm income. There are farm-operating expenses and numerous demands for farm equipment, additional livestock or improvements, and family living expenses, which can readily absorb the remaining margin of a year's cash returns, the only source from which saving can be made.

This practical difficulty of saving the cost of a farm may be greater after it has been bought than before purchase, although this is not always recognized when a mortgage contract is signed. Saving to pay off the mortgage under most mortgage contracts requires that payments of a uniform amount must be made every year, even though the year's production of crops or livestock may have been disappointing and prices for farm products may have been low. In contrast, savings before thé purchase of a farm may be made whenever there is a surplus available, and the amount may be different from year to year. The farmer who assumes a debt is obliged to plan his operations so as to insure the production of products that will give a cash return when the mortgage payment is due. If he raises livestock, it usually requires a longer period to mature and requires the investment of more funds, and he may have to sell his stock to meet payments. The result is that a smaller share of the produce grown on the farm is returned to the soil. The farm with a heavy mortgage is more likely to be used to produce wheat or other cash-grain crops rather than clover, alfalfa, or other soil-building crops, most of which are not sold for cash but are fed to stock. Under such a production system the soil becomes deficient in nitrogen and humus, and if the practice is continued over a period of time, it robs the soil and depletes the farmer's principal capital. Unfortunately, the results are not always apparent until the danger has become serious, when only a large investment would restore fertility to the land.

Abuse of the soil from credit causes may arise from any one of several situations. The most serious is the initial purchase of a farm at a higher price than is justified by the farm income in ordinary years. This was a common cause of difficulty in the farm depression after 1920. Regardless of lowered income a fixed mortgage payment continues to be required and every attempt to meet these requirements, even at the expense of the soil, may fail. Soil injury due to

an excessive credit burden is likely to be particularly serious just after a farm has been purchased, when the debt is large, few payments on principal have been made, and the family savings have been largely invested in the farm. Unfortunately, this situation is most likely to occur following periods of land boom, during which many farms are bought at high prices and debt is incurred.

Another shortcoming of traditional farm-mortgage practice in the past, emphasized in the depression of the 1920's, has been the short term of the typical mortgage loan. Brief terms of 3, 5, or 7 years were common until recently. In 1924, for example, 75 percent of all farm-mortgage loans had terms of 5 years or less. This system left the farmer with no alternative but to renew his mortgage loan at the end of its term on whatever conditions he could obtain, since a much longer period than 3 to 7 years is required to save enough to pay off the principal. Moreover, many of these loans were straight loans, requiring no annual reduction in principal, but making the full amount of the loan payable at maturity.

In important periods of American farm development the supply of credit has not been adequate for legitimate needs. In the early 1920's much refunding was possible, except in the worst areas, but in the early 1930's there was a great scarcity of funds until 1933–34. Many farmers have found it difficult or impossible to obtain a renewal of their outstanding mortgage loans when they fell due at the end of a short period. Much of this kind of difficulty has now been relieved by the introduction of loans for 30-year periods by the Federal land banks and certain private lenders, which also carry provisions for amortization by annual payments, usually of about 1 percent on principal. Notwithstanding this great improvement there are still many short-term straight farm mortgages in effect.

High interest rates, resulting in a charge in excess of the rate that could be earned by the farm, have been another handicap to farm ownership. In 1928, when outstanding farm loans averaged 6.1 percent for interest, mortgage rates in some sections of the country averaged between 7 and 8 percent. Although marked differences in the cost and risk of lending must continue to exist between areas, part of this difficulty in the past has been due to the unorganized condition of the mortgage market.

Danger From Too Low Interest Rates

Strangely enough, the difficulties of soil conservation and farm ownership may be increased as a result of very low interest rates in the financing of farms. Mention has been made of the effect of high land values in making farm purchase difficult for tenants and other farmers with small savings. One of the causes of high land values may be financing at low interest rates. Just as an investment is valued according to its earnings, farm land is worth what the income will pay interest on. If the net return per acre is $3 and the interest rate on loans is 6 percent, the farmer can afford to pay $50 per acre for the land. If the interest rate is 3 percent, the buyer can afford to pay $100 per acre for the same land, since $3 of income will pay carrying costs on a debt twice as large as when the interest rate was 6 percent. Consequently on every farm which acquires a loan at a lower rate of

interest, the capital value of the mortgaged part rises in proportion as the interest rate declines. Farms having favorable financing on their loans are more readily bought and sold than others. If the interest rate which the loan carries is especially low, a higher price will be paid by the purchaser. Low rates are an inducement to refund old loans to gain more favorable terms, and are an inducement to buyers to pay a higher price. It therefore happens that a low rate available for a sufficient length of time and applied to a sufficiently large proportion of farms may have the effect of raising the level of land values as the basis for loans and taxes. This process may raise farm-land prices to a level at which it is difficult for young farmers and others to acquire farms. Once the high land values are obtained they become the basis for larger amounts of credit, since the buyer's down payments from savings usually will be proportionately smaller and the mortgage given back to cover the cost must be larger. Even though no loan agency makes the loan, an enlarged debt may be created between the buyer and the seller reflecting the high value of the land.

The danger to soil fertility and ownership from high land prices becomes evident where land values decline. If, as in 1920, land values decline owing to a period of low farm returns which reduce the farmer's income, the indebtedness on the land is greater than can be obtained in a new loan based on the lower value of the farm. If the farmer is unable to pay the difference in the amount of the two loans, he may lose his farm and become a tenant.

Likewise, if the rate of interest rises and requires a greater amount of the farmer's income than he can afford, there is a reversal of the situation created by low rates. For if the farm debt is heavy and the rate of interest rises, the farmer's income will not pay the cost of carrying the credit obtained when rates were low. Difficulty of paying the higher credit charges may then cause the farmer to strain his resources, to make demands upon the soil which reduce its fertility, and in the end to lose his farm and become a tenant.

The least danger to soil and ownership on account of interest rates is likely to occur where there is a fairly uniform interest rate of such amount as will cover the cost of funds and the risk involved in the loan, which may be expected to continue over a long period of time, and which will permit the financing of the debt if necessary on a basis not greatly different from one period to another.

Effect of Farm Financing on Tenancy

The same conditions of financing that tend to result in deterioration of the soil also tend to make farmers lose their farms and hence to increase farm tenancy. A farm on which the soil is deteriorating is not only less productive but is a more difficult place for the owner to hold than a good farm, because it does not readily produce enough to meet mortgage payments. Moreover, if a substandard farm is purchased without adequate capital to build it up, it may be lost. If the farmer cannot meet the mortgage payments, delinquency will expose the loan to foreclosure, and the one-time owner may again be a tenant, having lost his savings in his poorly chosen or poorly financed farm investment.

The increased amount of tenancy found in the United States in 1938 is partly a result of the low prices through the long period of

agricultural depression that began in 1920, together with the fact that most mortgage-loan contracts made by farmers during the preceding boom period were not adapted to the economic conditions that developed. Foreclosure of mortgages in the years 1920–30 were high; in 1933, 5.4 percent; in 1935, 2.8 percent.

The adverse operation of depression forces after 1920 not only caused many owners to become tenants but also prevented many tenants from undertaking ownership. The burden of a fixed annual charge, which had caused neighbors to lose their farms, was effective in restraining many prospective purchasers from assuming the financial responsibility involved in buying a farm. Ownership and operation of a farm call for capacity in management and industrious application of the best practices. Even under favorable conditions many families find the undertaking too difficult. Hence under depression conditions, when there is an unfavorable relation between debt costs and farm returns, or in years when crops and prices are poor, even qualified tenants or sons of farm owners who want to operate a farm may be wisely reluctant to assume the responsibilities of ownership under the credit terms usually available.

LAND TAXATION

The heart of the farm- and forest-tax problem is the general-property tax. This is the one tax levied generally against rural real estate. Various other taxes are paid by rural landowners but have little or no direct influence on land use. The effects which the property tax tends to have on the use of land in rural communities may perhaps best be discerned by considering in order the total weight of this tax, its inherent nature, its practical operation, and finally, the nature of private uses of rural land.

Total Weight of Property Tax

Since colonial days, land (used in a broad sense to include buildings and other immovable improvements) has always been a major part of the tax base depended upon by local government. The State governments to a large extent have turned to other sources of revenue, but the counties, towns, school districts, and other units of local government still depend chiefly on the property tax.

This tax, which is tending to become more and more a tax on real estate alone, has borne the brunt of increasing needs for local governmental services. It has been generally utilized to make up deficiencies in revenue needed immediately to meet increasing costs but not available from other sources. Consequently, except in major economic depressions, the property tax has tended to increase continuously, regardless of intermediate fluctuations in property value. Property-tax increases, supposedly temporary, have become permanent, and when other sources of revenue have been developed for the announced purpose of relieving the property tax, they usually have soon been absorbed by new requirements.

Not only has the property tax borne a major portion of the requirements for local government revenue, but also these requirements are often needlessly high. As a rule, local government is not organized and administered in a manner fitted to modern conditions or in keep-

ing with the best principles of public administration. Modern invention has so improved travel and communication that units of local government which were once necessary to the convenience of the public have become much too small. Many of these districts are both too small to be efficient units of administration and too weak in resources to support properly the functions with which they are charged. Also in some States various special tax districts are superimposed on the local government pattern. The perpetuation of all these units results in the election and support of superfluous officeholders, duplication of machinery, diffusion of responsibility, and a generally poor quality of service at high cost.

For the country as a whole, and for nearly all States, farm-property taxes per acre increased greatly from 1900 to 1920. During that period, however, farm-land values as reported by the Bureau of the

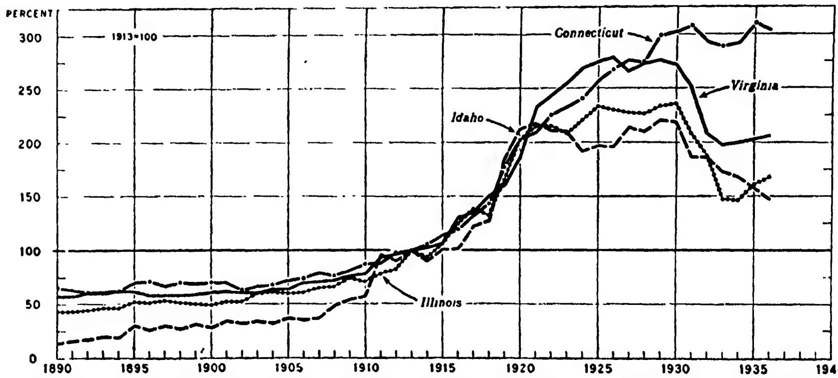

FIGURE 1.—Index numbers of farm real estate taxes per acre in four selected States, 1890–1936. The four State indexes shown here represent in a general way the form and variations in trends of farm real estate taxes for the 48 individual States. They do not represent extremes. For example, the series for some New England States rose higher than that for Connecticut; some South Atlantic State series rose higher and fell more rapidly than that for Virginia. Nevertheless all State series show this general shape, and a large majority of them cluster closely about the four represented here.

Census increased to nearly the same extent. From 1921 to 1929, farm-property taxes per acre for the country as a whole continued to increase slightly, although land values persistently declined. From 1929 to 1934, farm-property tax levies decreased about 36 percent concurrent with and following a devastating decline in farm income. By 1933 farm real estate values had turned upward, and since then have increased about 16 percent. This decrease in tax levies was not the result of decreased need for revenues, but rather of the inability of farmers to pay, as indicated by the tripling of rural real estate tax delinquency from 1928 to 1932. Apparently the convenience and elasticity of the property tax as a source of local public revenue, coupled with the high cost of local government, have brought about too great a reliance on this form of taxation (fig. 1).

The resulting weight of property taxes has a distinct bearing on rural land use. Where farm income in a given period is too low to support an acceptable standard of living, the farmer, of necessity, will

use every expedient to increase his current net returns. Such expedients are likely to include redoubled effort, concentration on cash crops, and destructive use of farm and forest resources.

The forest landowners, where the original timber stands are severely depleted, as they are in most parts of the country, also feel impelled to meet the current tax bill and other necessary carrying charges by selling any products available, regardless of the effect on productivity of the land, and to eliminate current expenses that are essential to protection and improvement. Property taxes thus encourage premature liquidation of timber and sale of cut-over lands for agricultural purposes regardless of suitability.

In short, too great reliance on property taxation in rural communities tends to promote short-sighted land use which, if persisted in, brings about serious deterioration of the land resources.

Inherent Nature of the Property Tax

To appreciate fully the effects of property tax apportionment it is essential to distinguish between those conditions which arise out of the inherent nature of the tax—effects which would follow even though the law were perfectly administered—and those which flow from imperfect or illegal administration. The inherent effects will be discussed first.

The base of the property tax is value, and value for this purpose is generally accepted as voluntary exchange value, reflecting present worth of expected future income. Accordingly, the base of the property tax does not fluctuate with changes in income from one year to the next. Taxes are payable whether or not income is available for this purpose in the particular year. The lack of response of property-tax levies to current receipts of income, while an advantage from the public revenue viewpoint, will under some circumstances be a disadvantage from the standpoint of developing far-sighted land use.

The case is less serious where the deficiency in income is only for a year or two, but it may become extremely serious where the deficiency is long continued. Extended income deficiency occurs generally in respect to all lands in times of severe economic depression. It is also chronic in respect to certain types of land in their present condition, such as forest land that has been so severely depleted that the process of restoration to full productivity requires many years.

If all land were yielding a regular annual income, a universal and perfectly administered property tax would take the same percentage of income from all land and would merely reduce the amount of the net income available to the owner. It would have little or no direct influence on land use. The only way it could destroy private ownership would be by the levy of taxes equal to or in excess of income. Assuming a gradually increasing tax rate, it could not theoretically take the entire income and thus destroy private ownership, because value would fall as the tax rate rose, and even a high rate based on the residual value would leave a part of the income to the owner. Whether income is realized regularly or is deferred, the property tax merely divides the total value (which the property would have without imposition of this tax) between the private owner and the public. Where there is possibility of competition for land between uses involv-

ing either current or deferred income, even this perfectly administered property tax will tend to force land into uses yielding current income with which to pay the annual tax bill. Such a tendency may be socially desirable so far as it concerns certain classes of real estate like vacant city lots. It may also have been desirable in stimulating the development of a major portion of agricultural, mineral, and other lands now established on an economic basis.

But the period of such development is now largely past. At present the effect of the property tax on rural lands that do not yield a uniform flow of income is generally adverse. Its influence is toward increased production of annual cash crops by excessive and undesirable use of the land resources. As a result of the cash requirements for current operation, to which this tax contributes, and the short-term fluctuation in economic conditions, a wide margin of the poorer land in one farm ownership is likely to be shifted from one use to another so frequently as to lose much of its possible usefulness in building up reserve resources for future utilization. Temporary improvements and operating facilities are overemphasized; permanent maintenance and improvement of physical capital are neglected; lands fit only for permanent pasture or woodland are broken up; wood lots are pastured, neglected, or cleared; timberlands are operated by methods which destroy the growing stock necessary to continuous production. It is not intended to imply that where these conditions are found taxation is necessarily the sole or chief cause; taxation is, however, an important contributing cause.

Aside from the facts that the property tax is an inescapable annual charge regardless of current income and that it is subject to unpredictable changes of rate, an element of uncertainty as to its amount is added through the tendency at times for land values to become distorted by speculative excesses or widespread misconception of future land use. Assessors often ignore local or sporadic speculation, although where exchange values are clearly affected they are required by law to recognize this condition in assessment. Where the speculative fever is widespread and violent, as in Florida in 1925, the swollen condition of the tax base has led to uneconomical construction of public improvements and extravagant expansion of public services. The ultimate result, when the speculative booms have subsided, has been extensive tax delinquency and bankruptcy of local governments. Sometimes only one class of land is affected. Thus, cut-over land in the Lakes States, which is now generally recognized as suitable only for recreation and forestry, was at one time mistakenly considered to be potential agricultural land. As a result of this misconception a tax burden was imposed on this land above that which the business of forest growing could bear and uneconomical attempts at agricultural development were encouraged. When the true character of the land became generally apparent, these attempts were abandoned and widespread tax delinquency followed. On the other hand, current land use and corresponding price may in some instances ignore certain income possibilities, in which case the tax base is low and owners are encouraged to hold the land out of the most suitable use. This situation is not often found, however, in rural communities at the present time.

Undoubtedly a well-considered shift in the use of land is often desirable. Frequently land-use zones have been altered under pres-

sure of changing price relationships that have caused farmers to change their type of farming. On the other hand, society has suffered significant losses through unwise development and later destruction or neglect of orchards, irrigation systems, drainage areas, and forests, as well as by speculative holding and neglect of land which should be developed and productive. Unnecessary shifts are expensive. For example, fluctuation of land between farm and forest use usually leads to inadequate returns from either type of utilization.

Where income deferment is necessary in order to build up the productive capacity of the land, it may be difficult to finance the annual property-tax bill. Furthermore, the portion of income taken by this tax, even if the tax is perfectly administered in accordance with the law, is greater than in the case of property which yields a regular annual income, through the necessity of paying taxes in advance of the receipt of income. These features could well be disregarded were equity alone at stake, since the investor in deferred-income properties, knowing the character of the property-tax system and the necessity for income deferment, may be presumed to pay a correspondingly less sum for such a property, thus offsetting the effect of the expected tax burden. From the land-use viewpoint, however, the disadvantages of paying taxes over a period of years prior to receiving income are important. Where the land may be used in different ways, the effect of the property tax is to favor the use which yields a regular annual income against that which requires deferment of income. This result is especially discouraging to the use of land for growing forests.[2]

Small and intermediate forest properties often afford substantial harvests only at infrequent intervals, because in many cases it is impossible to market at a profit the production from only a few trees at one time. It is not always practicable, therefore, to manage such properties to receive annual income sufficient to pay charges. Large properties, as well as smaller tracts with access to favorable markets, may be so managed eventually, but where the forest has been badly depleted of timber, the typical condition in this country, a long period may be required before a sustained yield is possible.

In other words, it is usually necessary to defer receipt of substantial income over a period of years in order to bring the forest back to a condition where there are enough trees of different sizes so that a harvest of the larger trees may be obtained annually or at short intervals. If prices of timber on the stump were closely responsive to the cost of growing such timber, the disadvantages of deferment or irregularity of income might be overcome by increased returns. Stumpage prices are not so responsive, however, partly because of substantial old-growth timber supplies, inherited by society without charge for growth. Thus, whenever a portion of an existing forest is to be cut, the question arises whether it would be more profitable to maintain the forest as a going concern, or to begin breaking it up after the cutting, putting the land to other uses or allowing it

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[2] This conclusion assumes, however, that the income from annual-yield use will not become subject to the tax. Either this income will be consumed or it will be saved in some form to escape the tax, at least in part. In other words, the differential burden applies to all investment or savings, and deferred-yield properties are a type on which accruing gross income in a physical sense is perforce saved as added investment. D. J.

to revert to public ownership. The property tax exerts a direct influence on the decision in such cases. Of course, fluctuation in prices and other factors also exert an influence.

A forest property from which the timber has just been cut may, without taxes, be worth more for continued timber production than for an annual-yield use such as grazing. Subsequent imposition of a property tax will nevertheless reduce the timber-growing value more than it will the annual-yield value, and may make the property worth less for the deferred-yield use.

As an example of the effect of the property tax on land use, consider a forest property from which the timber has just been cut. Assume that this property would have a value, if no tax were imposed, of $5 per acre for a deferred-yield use such as forestry and of $4 per acre for some use, like grazing, that would yield an annual return. But if a property tax is imposed, the ratio of taxes to net income before taxes (both compounded or discounted to the same point in time, and both covering the same income cycle) in the case of the deferred-yield use may be 40 percent—a very common tax ratio among forests—and in the other case perhaps 20 percent. Since the effect of the tax would be to reduce the value before its imposition in proportion to the expected reduction in income, the value for the deferred-yield use is under these circumstances reduced to $3, and for the annual-yield use is reduced only to $3.20. Thus the margin for deferred yield has been so shifted that areas that would be used for forestry were it not for this effect of the property tax are now available only for grazing or other use yielding annual income.

This feature of the unmodified property tax tends toward use of lands for grazing or cultivated crops which from a long-time point of view are better adapted to forestry.[3]

Faulty Administration of the Property Tax

So far, only the effects of the property tax under theoretically perfect administration have been considered. In everyday operation, this tax is a very different thing from the ideal property tax contemplated by the spirit of the laws which govern it. Some aspects of its ordinary operation as distinct from its theoretical effect are likewise adverse to making the best use of rural lands.

It is evident that a fair assessment is essential if the property tax is to work out as contemplated. All studies of assessment practice have shown that, in most localities, there is a high degree of inequality of assessment among individual properties. Many causes of such inequality have been found. Without discussing them in detail, it is sufficient to note that they include lack of expert judgment on the part of the assessor; inadequate information in the assessor's office; pressure to favor certain individuals or groups of owners; inadequate provision for the necessary cost of careful work; and lack of provisions for classifying land, especially within a property or parcel.

The nature of the inequalities usually found is of importance and deserves consideration from the viewpoint of land use. It has been found in studies of assessment practice that there is an almost universal

[3] The tendency results from the desire to avoid exposing an investment of increasing size to the burden which the property tax places on real estate. D. J.

tendency to overvalue lands of low price per acre in comparison with those of high price. One of the reasons for this tendency may be a natural inclination of the assessors to rely too much on average figures, so that property is likely to be overassessed if under the average price and underassessed if over the average. Whatever the causes, this tendency to overburden property of low value operates to the disadvantage of poor farm lands and of cut-over and immature forests.

The illogical apportionment of functions among units of government also brings about inequalities in the property-tax burden. Property taxes are levied by various types of jurisdiction, many of which are overlapping—such as State, county, town, and village, and school, road, and drainage districts. An individual property may lie in one or in a number of these districts, one superimposed upon the other. Benefits do not correlate with geographic limits of districts, and often the properties within a district do not benefit equally. As a result, there is likely to be marked inequality of taxation, not only among communities in the same State, but among the properties in any one community.

Inequalities in taxation that would not be very important with low property-tax rates become serious indeed when these rates are high. It is apparent that in most States there is an unwarranted difference in tax rates among different localities, when such rates are adjusted to the basis of actual value to permit fair comparison. Abnormally high tax rates often lead to tax delinquency, and when applied persistently to assessments in excess of actual value tend to force land out of private ownership. Sparsely settled communities and those not favored by nature with rich resources are especially likely to suffer from these conditions. Such communities are frequently in land-use problem areas which can ill afford this added burden tending to misuse of land.

Tax-collection procedure may be a cause of inequality, if it becomes dilatory and inefficient. In recent years the heavy weight of taxation, greatly increased by the depression, has brought about a tendency to extreme leniency toward delinquent taxpayers. Such leniency has been carried in some States to the point where there is positive inducement to let real-estate taxes go unpaid. Where inefficient collection thus encourages tax delinquency, it often results in the levy of additional taxes on the lands whose owners continue to pay. Inequalities resulting from defects in tax-collection procedure, like those from faulty assessment and illogical apportionment of governmental functions, tend to promote undesirable shifts in use of rural land and to hinder needed readjustments in areas where land-use problems are critical.

Nature of the Farm and Forest Enterprise

It may be observed that many of the disadvantages of the property-tax system that have been cited affect urban as well as rural property. For example, there may be too great a reliance on the property tax in urban as well as in rural districts. It is difficult to make a fair comparison of the burden of taxation per dollar of property value as between rural and urban communities. Proper account must be taken of the differences in governmental services rendered; and the

various tax rates, applied to assessments representing variable portions of actual value, must be adjusted to a comparable basis. For the purposes of this discussion it is unnecessary to make such a comparison.

The significance of taxation from the land-use viewpoint is not principally concerned with relative tax rates or burden of taxation per dollar of real-estate value, but with the effect on urban and rural enterprise. Urban enterprise usually involves a relatively large investment in capital instruments that are only in part subject to property taxation, while the typical rural enterprise, in either farming or forestry, requires a relatively large investment in real estate.

Not only is it true that where property-tax rates are high, the public equity in real estate is high and the private equity low, but the property tax constitutes essentially a fixed charge, that is, one that must be met before providing for other requirements. If much of the investment is in real estate, the financial difficulties of the enterprise as a whole are intensified. Any enterprise that is subject to a relatively high fixed charge against its income is peculiarly vulnerable to economic disturbances, unexpected increases in taxation, and other unfavorable developments, since the relatively small portion of expected private income is easily wiped out. Also, capital invested in real estate can usually be liquidated only at considerable loss if changes in the tax situation or other factors make the enterprise unattractive. There are periods such as the early 1930's when farm lands could be sold only at great sacrifice.

In most regions there is always a poor market for young forests, the products of which would be merchantable only after a period of years. Accordingly, high property-tax rates, especially when subject to erratic administration, introduce a heavy element of risk and are more of a deterrent to rural than to urban enterprise. This element of risk aggravates the tendency toward current exploitation of the land resources and discourages their conservation and development for sustained production.

When the property-tax system grew up in this country, the need most felt was for immediate development rather than for conservation. The demand of the present and the future is for restoring the wastage that accompanied this development. This demand calls for some modification in the tax system together with more direct measures to promote the improved utilization of our land resources.

IN ADDITION to the factors that can be shown to have a direct influence on soil use, for good or ill, there are many factors that have an indirect influence, less easy to trace but overwhelmingly important. They are the profound economic maladjustments and disturbances that affect the world today. Who can doubt that what the farmer does with the soil is strongly influenced by instability of farm production, prices, and income; the dislocation of international trade that followed the World War; the recurring cycle of business boom and depression—particularly the great depression of 1929; and the relations between agricultural and industrial production and prices? In this economic area are the toughest problems the farmer has to face. This article outlines some of the factors with which he must deal in his thinking.

The Causes: Price Relations and Economic Instability

By Louis H. Bean, J. P. Cavin, *and* Gardiner C. Means [1]

INSTABILITY OF AGRICULTURAL PRODUCTION, PRICES, AND INCOME

IN THE United States there are wide areas where agriculture—natural resources, soil fertility, and human resources—has suffered from fluctuations in prices and income and from inadequate income. Instability of income traces to abnormal variations in weather and to variations in crop acreages, in domestic and foreign demand, and in purchasing power. The narrowing of the fluctuations in farm prices and of the margin of uncertainty as to prices and yields per acre, together with a general improvement in returns, would make it possible for more farmers to use soil-conserving measures and farm-management practices that meet the standards of current agricultural science.

The wide fluctuations in crop prices and returns during the past generation have been responsible for the opening up of land to speculative farming without sufficient regard for the maintenance of fertility. They have served to restrict the amount of money indi-

[1] The section headed Instability of Agricultural Production, Prices, and Income is by Louis H. Bean, Economic Adviser, Agricultural Adjustment Administration. The section headed International Relations and National Monetary Policy is by J. P. Cavin, Agricultural Economist, Production Planning Section, Agricultural Adjustment Administration, and the section headed The Nature of Competition in Agriculture and Industry is by Gardiner C. Means, Director, Industrial Section, National Resources Committee.

vidual farmers could use for long-time investments and improvements. The low level of farm income per capita in relation to nonfarm income that has prevailed since the World War, as well as many of the present soil-conservation problems in the Great Plains and other areas, may be traced in part to the impetus given to production by the abnormally high prices resulting from the war. All of the important factors that influence farm income and the ability of farmers to deal efficiently with the soil, such as weather, foreign trade, domestic demand, and the commodity price level, have borne more heavily on farmers during the 1930's than during the 1920's.

Instability in Acreage

In contrast to industrial activity, agricultural production is generally considered to be relatively stable. The fact that the total acreage planted to crops does not vary a great deal, in sharp contrast with the great fluctuations in industrial production and employment, is somewhat misleading, for many individual farmers do attempt to adjust their crops and their livestock to changing prices. The instability in crop acreages is partly hidden by the fact that when thousands or millions of farmers make individual adjustments, many curtail crops that others find it beneficial to increase. The Corn Belt farmers might decrease their acreage in corn because of low prices for corn or hogs and find that their action has been offset by an increase in corn acreage in the Wheat Belt because the winter wheat crop was killed, or by an increase in the South because cotton prices are low.

A great deal of acreage instability is hidden in the relatively stable aggregate of 359 million acres planted or harvested in 1925, 368 million in 1930, and 373 million in 1933. A few examples will suffice to show the nature of the instability in acreage. In 1922, after several years of high prices, potato acreage was expanded to 3.9 million; by 1925 the increased production and lower prices brought the acreage down to 2.8 million. By 1932, relatively good prices, as well as efforts on the part of farmers and gardeners to become more self-sufficient, restored potato acreage to 3.5 million. In the case of cotton, the post-war low prices of 1920 brought the total acreage down to 28.7 million, and subsequent high prices brought an expansion, chiefly in the western Cotton Belt, to 44.6 million. The declining prices after 1926 brought cotton acreage down to 35.9 million in 1932. In wheat, the high wartime prices brought a rapid expansion in acreage seeded to a record of 77 million, and the subsequent low prices reduced it to 55 million. By 1928, 71 million acres were again seeded to wheat and by 1937 there was another record of more than 80 million. These shifts in the national acreages of individual crops are as great as the changes in many nonagricultural industries, and the year-to-year shifts in acreage in individual crops in individual States are even more pronounced.

Instability in Yields

What the weather has done to farmers may be inferred from the recent changes in yields per acre of the major crops. In the case of corn, the yield per acre during 9 of the 11 years 1919–29 ranged between 26 and 28 bushels, with 1 year's yield as high as 30 bushels

and 1 year's as low as 22 bushels. In the 8 years since 1929 there have been only two normal crops of 26 to 28 bushels per acre, four crops moderately below average and two record-breaking short crops in 1934 and 1936. Corn Belt farmers are now wondering whether the swift succession of droughts marks the beginning of a prolonged period of low yields or a period of greater weather fluctuations and greater variability in yields per acre.

The wheat growers likewise are baffled by the probable course of the weather more than ever before. Wheat growing has not in the past been free of various hazards. There were near crop failures in 1925, in 1917, in the 1890's, and in the 1870's, but in the official records of over 70 years there is no record of a succession of droughts as prolonged as that in the 1930's. During 10 of the 11 years 1919–29 the average wheat yield per harvested acre ranged between 13 and 15 bushels and in only 1 year was as high as 16 bushels. Since 1932 there have been four poor crop years out of five, with yields below 13 bushels per acre.

Just as the grain region has been suffering from adverse weather conditions that have tended to pull down the average level of yields, the South has been suffering from a trend in the opposite direction.

Following the spread of the boll weevil over the entire South by 1920, the trend in the average cotton yield per acre has been upward. After an extremely low output of 132 pounds per acre in 1921, the South experienced an abundant yield of 193 pounds in 1926, two nearly record yields in 1931 and 1933, good yields in 1934–36, and a record yield of 264 pounds per acre in 1937. The 1937 record yield was exactly 100 percent greater than the low yield of 1921.

These examples of instability in yields per harvested acre tell only part of the story. Another part is the wasted effort and the money costs involved in planting acres that are not harvested. During the 11-year period 1919–29 the total acres in nine crops planted but not harvested usually amounted to about 5 to 9 million and in only 2 years to 11 and 14 million acres. But in 1931 the total abandonment reached 15 million; in 1934, 43 million; and in 1936, 45 million. In 1937 abandonment was reduced to 24 million acres, or twice as many as in the worst years before 1929.

These facts as to the greater instability of crop production in recent years due chiefly to the influence of weather and other factors on yields per acre are shown clearly in figure 1. The line showing the variations in the yield per acre is matched very closely by variations in total crop production.

Instability in Storage Stocks

Instability in crop production does not exert its influence entirely in the year when fluctuations take place. The good or ill that results from the size of a crop often affects the money returns of subsequent crops. This is particularly true of cotton and wheat, supplies of which may be carried over from one year to the next. The domestic as well as foreign consumption of these commodities varies relatively little compared with the wide variations in production. Bumper cotton crops, for example, result in an increase in the carry-over, and this serves to depress prices for 2 or more years until the excess stocks

are brought down to normal. Even when farmers attempt to curtail their production after a bumper crop, the additional carry-over may be so large as to more than offset the amount of the reduction. This may bring about a situation where the price does not rise in proportion to the reduced crop, and farm income is consequently less than for the previous large crop. Such a situation actually developed in 1937-38 when the expected reduction in production of 1938 was more than offset by the increase in stocks of more than 6 million bales due to the 1937 record crop.

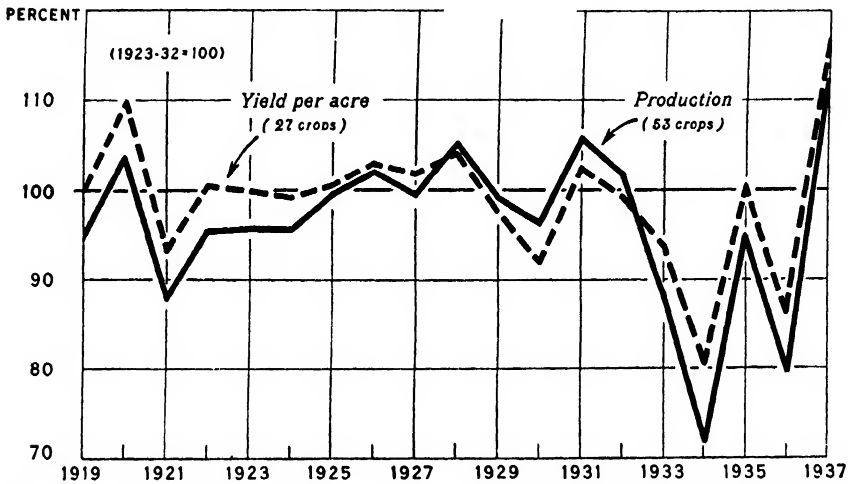

FIGURE 1.—Greater instability in crop production in the 1930's than in the 1920's.

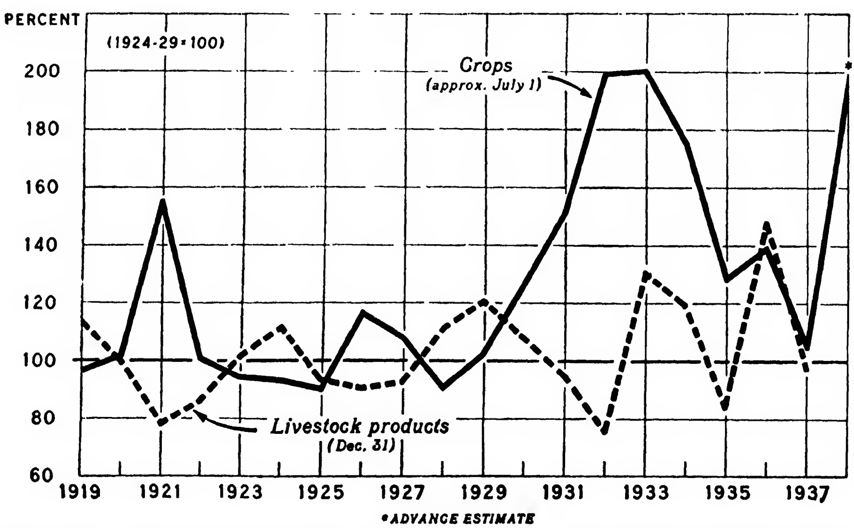

FIGURE 2.—Instability in storage stocks of crops and livestock products in the United States, 1919–37.

The variations in stocks since 1919 are shown in figure 2. Stocks of crops, chiefly cotton and grains, mounted to abnormally large volumes in 1931–33 as farm production continued relatively large in the face of falling domestic demand for cotton and falling exports of grains. By 1937 the abnormal weather and improved industrial conditions and production adjustment programs had reduced crop stocks close to normal, but the record cotton crop of 1937 and the large 1937 wheat crop without adequate foreign demand restored stocks in 1938 close to the large stocks of 1932–33.

The fluctuations in storage stocks of livestock products have been roughly cyclical in character, reflecting in large part the cycles in hog production. In recent years they have fluctuated more widely than in the years 1919–29, the range of variation being approximately 80 to 120 percent of the 1924–29 average and 75 to nearly 150 percent in the 1930's, or about twice the range of the 1920's.

Instability in Foreign Trade

The foreign outlet for United States farm products has been a very important factor in farm income and has had a great deal to do with the present state of depleted soil fertility and the many abuses of farm land. It is significant that there is such a close correspondence between the areas in the United States that supply most of the farm exports, the areas of lowest per capita income, and the areas of abused and mismanaged farm lands. In some years, farmers have been paid handsomely for shipping their soil fertility abroad. There have been years when large exports have coincided with shortages and high prices abroad. The World War period was the outstanding example. There have been other years when our record crops have been sold abroad at prices that made the large crops worth less than the smaller ones. This has been more often true of record cotton crops than of large wheat crops.

The general characteristics of the instability in our foreign trade in farm products are shown in figure 3. During the past 70 years there have been three major fluctuations in exports about 20 years apart, one reaching a peak about 1880, another reaching a peak about 1900, and a third reaching a peak about 1920. These swings are especially marked in the total of exports, excluding cotton—chiefly exports of grains and livestock products. Thus every generation since 1870 has experienced wide fluctuations in export demand and in the volume of exports, but the present generation has experienced the greatest instability. The decline in exports (excluding cotton) after 1880 was about 35 percent, the decline after 1900 about 60 percent, and the decline after 1919–20 about 80 percent. The practically continuous decline after the World War, especially in the exports of grains and livestock products, was one of the factors which helped bring on the depression of the 1930's, for it lowered the returns to that part of United States agriculture that depended to a large extent on international trade and kept agriculture from sharing fully in the post-war prosperity that terminated in 1929.

It is important to observe that the upsurge in exports in each of the past three generations has been the result of the opening up of new lands and that the most recent peak in exports, associated with the

World War, was made possible by a shift of the Corn and Wheat Belts westward into less productive land that probably is better adapted to grass farming. The quick rewards of the war days have since given way in the Great Plains region from Canada to Mexico to losses due to drought and wind erosion.

Instability in Domestic Demand

The instability of income due to changes in industrial activity and domestic demand has also been much more of a problem for farmers in the 1930's than in the 1920's. This holds true whether domestic

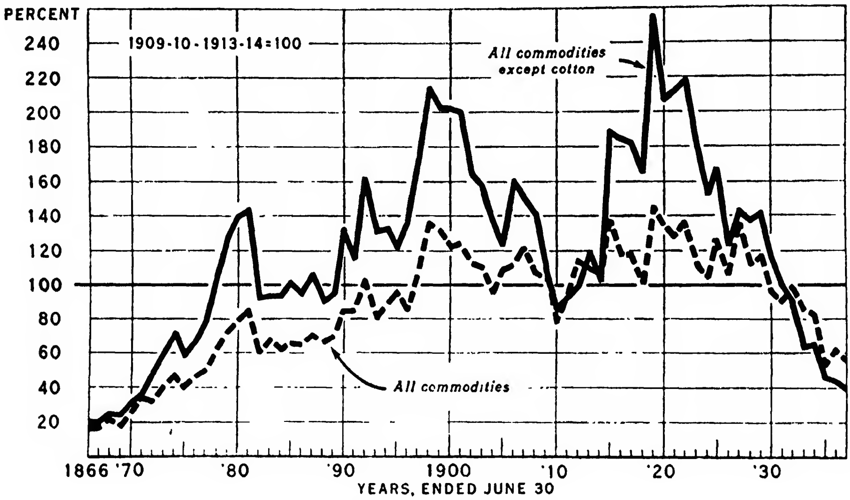

FIGURE 3.—Volume of agricultural products exported from the United States: Index numbers, 1866–1937.

demand is measured in terms of physical volume of industrial production or in terms of the money income of consumers. Two illustrations will reveal this fact of increasing industrial instability. The South depends on the general level of industrial activity to maintain the domestic consumption of its chief crop, cotton. In figure 4, this dependence is seen clearly in the way cotton consumption by mills goes up and down with general industrial production. It is also clear that the swings in consumption in 1929–33 and 1933–37 were much greater than those of 1920–23 and 1923-27.

The South perhaps as much as any other agricultural section has apparently shared in the increasing instability of industrial activity. Throughout the rise of iron and steel as a basic industry in the development of the railroads, the automobile, and other so-called durable-goods industries, business activity has become more and more unstable. In the depression of the 1870's pig-iron production fell off only 25 percent, in the depression of the 1890's 35 percent, in the 1921 depression 55 percent, and in the 1932 depression 80 percent. Cotton, used in large measure by other industries, has experienced this increasing instability in domestic demand.

Other sections of agriculture, particularly those producing livestock and livestock products and other commodities consumed chiefly in the domestic markets, depend on the flow of money income into the hands of consumers. For the country as a whole, retail expenditures for dairy and poultry products and meats go up and down with consumers' total money purchasing power, indicating that a fairly constant proportion of the Nation's spending power goes for livestock products. The extent to which this has held true for pork is shown in figure 5, in which the course of annual retail expenditures for pork is seen to

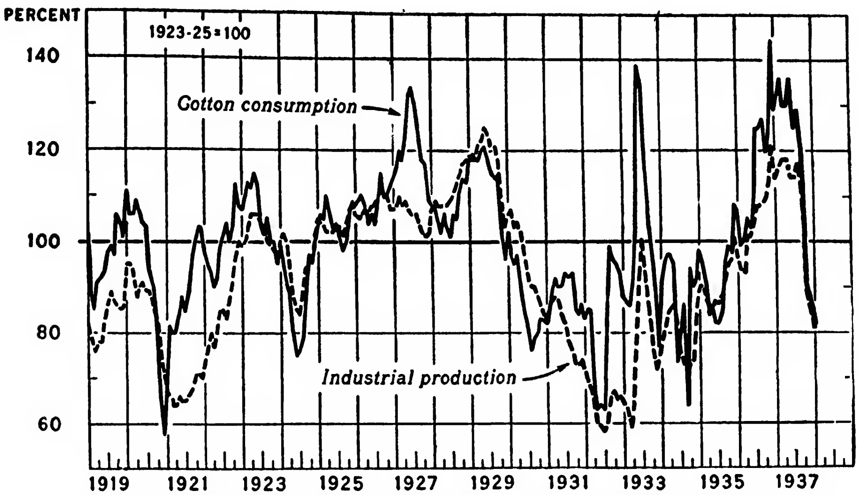

FIGURE 4.—Cotton consumption and industrial production in the United States, 1919–37.

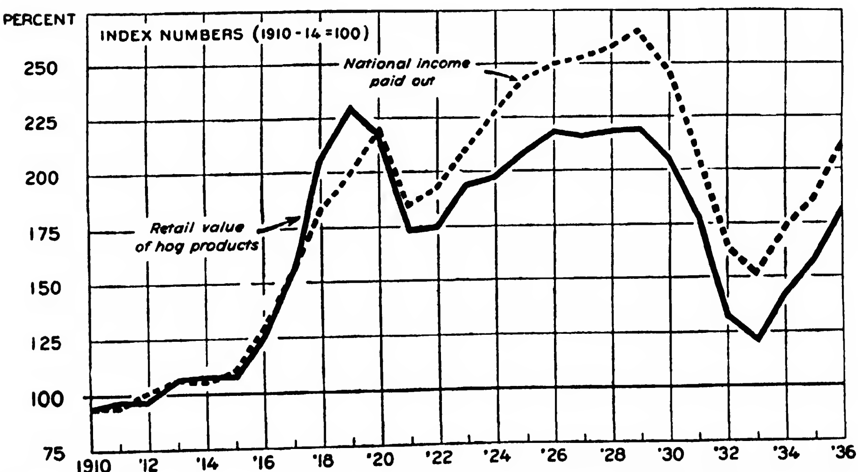

FIGURE 5.—Retail value of hog products consumed and national income in the United States, 1910 to date.

parallel very closely the stable course of the national income before the war, the marked rise during the war years, the moderate decline in 1921, and the wider fluctuations after 1929.

The increasing instability of consumer purchasing power and retail expenditures for foods means even greater instability in farm income. This springs from the fact that approximately half of the consumer's dollar goes to the farmer. Probably half of the farmer's share is paid out for production costs; and inasmuch as the distribution margin tends to remain relatively stable, declining retail expenditures tend to reduce the farmer's share and rising retail expenditures tend to

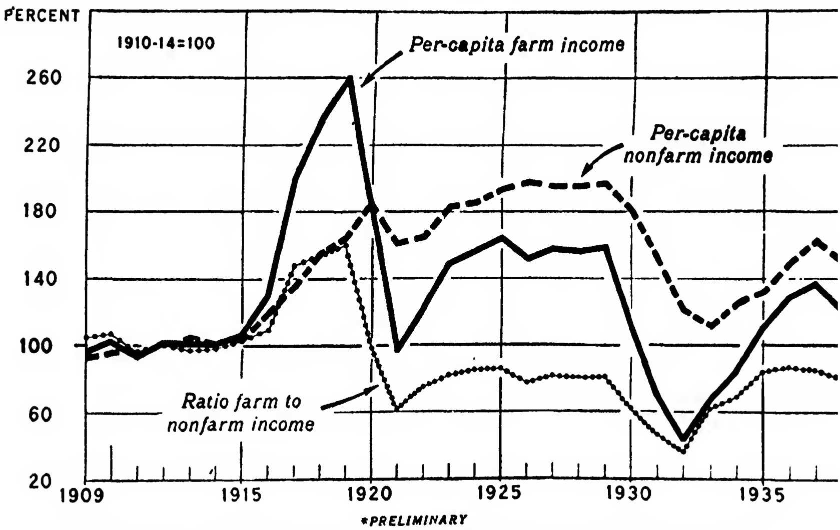

FIGURE 6.—Per-capita farm and nonagricultural income available for living, 1909–38.

increase it. For example, in the case of a commodity priced at $1, a 20-percent reduction in the consumer's price, if it is all taken out of the farmer's half, means a 40-percent reduction in the farmer's gross receipts; and an increase of 20 percent in the consumer's dollar price, if it all goes to the farmer, means a 40-percent increase in his share.

Partly for this reason, partly because distribution and farm production costs have remained relatively high ever since 1920, and partly because of the rise and fall in foreign demand, there has been only a moderately close correspondence between the course of total per-capita income from farm production and the per-capita income of the nonfarm population. In figure 6 it is shown that per-capita farm income, after certain production expenses were deducted, rose about twice as much during the war years as per-capita city income available for family living; that the latter remained on a relatively higher level throughout the post-war period, farm income being held down partly by relatively high debt and tax charges, relatively high production and distribution costs, and falling foreign demand. It is clear that but for the brief period of relative advantage that farmers

enjoyed during the war years, their incomes have been substantially short of parity with urban incomes throughout the 1920's and 1930's. One of the objectives of the farm programs after 1933 has been to close this disparity between farm and urban per-capita income.

Instability Due to Inflation and Deflation

In addition to the instability of weather, foreign demand, and general business conditions, there is also the instability of monetary and credit conditions, which brings about great variations in the general level of commodity prices. This type of instability, particularly

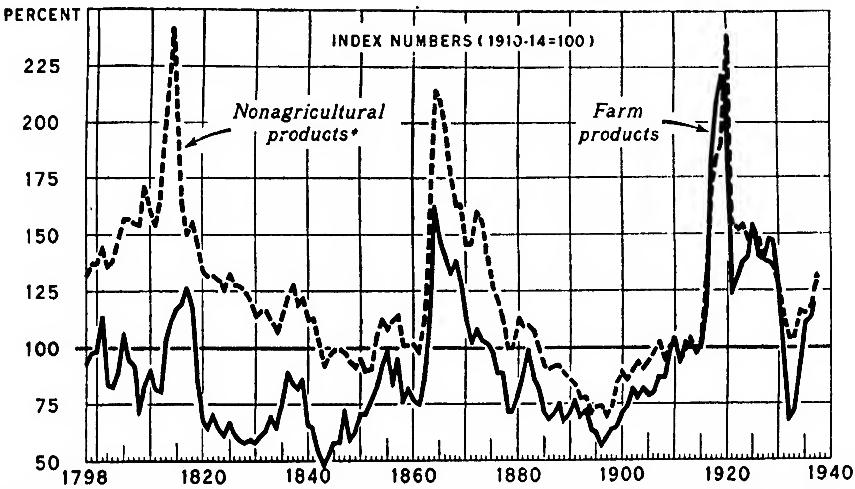

FIGURE 7.—Wholesale prices of farm and nonagricultural (all commodities other than farm products and foods) products, 1798–1937.

war inflation, is perhaps the worst that any generation of farmers can be afflicted with, for it not only distorts price relationships and the judgment of farmers as to what they should do with their land and their income, but serves through its consequent deflation to undermine agricultural welfare for many years.

Since 1800 we have experienced three major wartime price inflations. What happened to both agricultural and nonagricultural prices during the period of the Napoleonic wars and the War of 1812, during the Civil War, and during the World War is clearly shown in figure 7. During the first of these episodes, prices of farm products rose from an index of about 75 in 1808–9 to 125 in 1817, a rise of 66 percent. Between 1860 and 1864 they rose from an index of 75 to 162, an advance of 110 percent; and between 1914 and 1919 they advanced from an index of about 100 to 220, an increase of 120 percent. This increasing instability in wartime inflation periods seems also to be characteristic of the deflation periods. Between 1919 and 1932, farm-product prices fell about 70 percent compared with a decline of about 55 percent during the comparable period after the Civil War.

The instability of prices during the intervals of peace are also clearly shown in figure 7. Note particularly the advance in prices in

the 1830's associated with the credit expansion and land boom of that period; the advance in the 1850's following the opening of the far West by the gold rush of the late 1840's; the advance after 1879 associated with the credit expansion following the resumption of specie payments for paper currency; and the advances after 1921 and 1932.

The increasing instability in farm-product prices would have somewhat less drastic effects on farmers if prices of industrial products showed similar flexibility. While industrial prices have been affected by wartime inflations, as were agricultural prices, their short-time

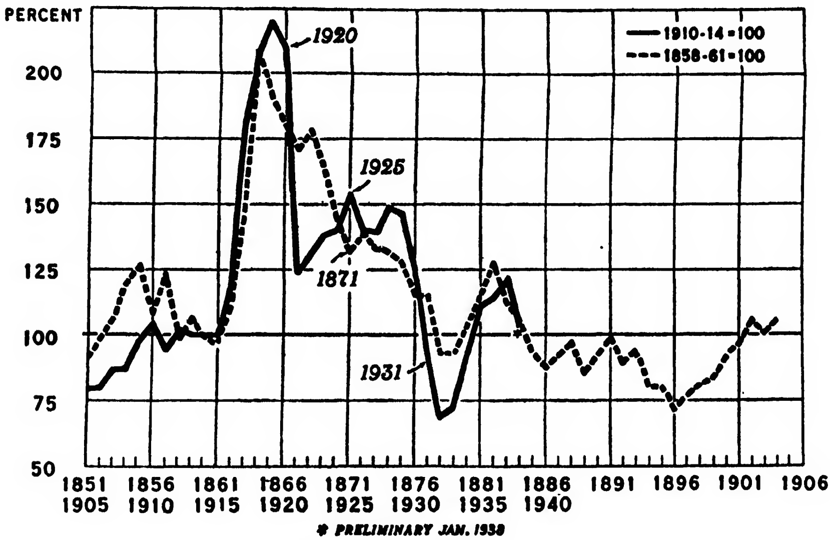

FIGURE 8.—Index numbers of wholesale prices of farm products for two periods, 1851–1904 and 1905–37.

fluctuations are not as marked (for some of the reasons stated above and those discussed in the section, The Nature of Competition in Agriculture and Industry). Note, for example, the greater fluctuations in agricultural prices in the periods 1843–60 and 1921–32. Consequently, the purchasing power of agricultural prices has been much more erratic since the World War than it was after the Civil War. By 1932, for example, the purchasing power of farm-product prices was only 66 percent of what it was in the pre-war years of 1910–14, whereas in 1878 it was about 90 percent of what it had been just before the Civil War.

The contrast between the instability of inflation and that of deflation can be seen clearly in the course of farm-product prices of the Civil War and post-Civil War period and the World War and post-World War period. In general, the period of inflation is short compared with the prolonged period of deflation. In figure 8, where the price movements of the period 1905–38 are superimposed over those of 1851–84, the inflation episodes lasted only 3 to 4 years, whereas the deflation period in each case was one of a prolonged irregular down-

ward trend of prices. So far the post-World War decline in prices of farm products has duplicated in large measure the decline in agricultural prices after 1864. If this parallelism were to continue, prices of farm products would on the average during the next few years tend to remain below the prices of 1936 and 1937; for the higher prices of 1936 and 1937, like those of 1881 and 1882, were affected by unusually small crops and business recovery.

The long-time upward trend in farm prices (like that after 1896) and the short-time inflation periods followed by prolonged deflation originate a flow of labor and capital into agricultural production that leads to much distress. Farmers, professional people, and small-town

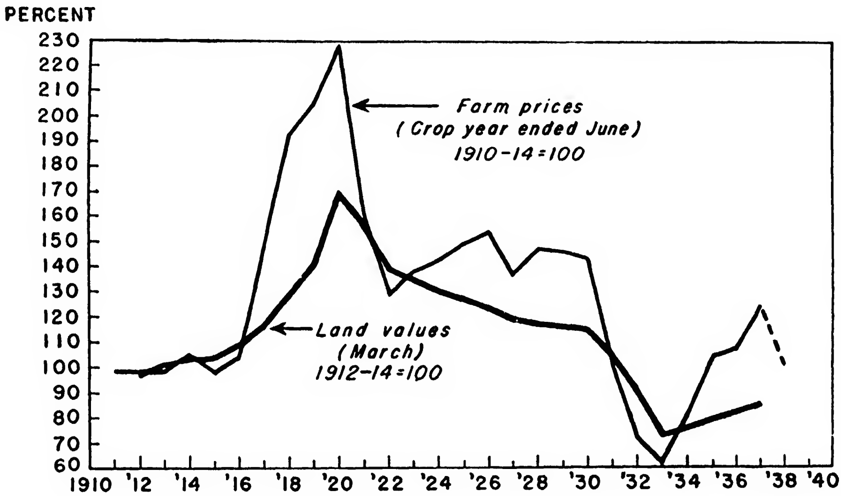

FIGURE 9.—Trends of farm prices of commodities and of land values, 1910–38.

business men have in the past purchased land expecting land values to rise, thus paying more than current farm income would justify. Up to the World War, land values had risen for a generation without any real interruption. On the basis of this experience, many persons lost their heads and subsequently their savings as they banked on a continuation of the high wartime prices. Farmers, tenants, and many city people, as prices tumbled and took land values down with them, were left with mortgages that could not be met with reduced earnings. How the wartime rise in prices received by farmers lifted land values and how they have since caused land values to drop downward is shown in figure 9. In many ways the inadequate incomes during the post-war deflation period tended to affect soil use and farm-management practices. For example, the increase in farm tenancy which accompanied the rise in prices and land values meant an increase in systems of farming that exhaust soil resources, for tenants are known to follow such systems more than do farm owners. The pressure of debt and taxes undoubtedly prevented thousands of farmers from utilizing adequate crop-rotation systems, fertilizer, and other soil- and fertility-conserving practices.

Instability in Separate Commodities

The instabilities in agriculture due to changes in the general level of commodity prices and changes in domestic demand tend to affect all farmers alike. In other respects there are broad differences in the effect on producers of instabilities in the several branches of agriculture, depending partly on whether they are producers of annual crops or of livestock, and whether the production cycle is short or long. These differences may be illustrated by the course of prices of several of the major farm products, with the effect of the general level of commodity prices eliminated.

In the case of cotton, in spite of the fact that it is an annual crop, the combination of price-making factors has produced something of a cycle in cotton prices. Measured in terms of what cotton would buy in the way of industrial products at wholesale, swings in cotton prices have been approximately as follows, with an interval of about 6 years between the years of low cotton prices:

Years of low cotton prices		*Years of high cotton prices*	
1914—7 cents	1932—5 cents	1918—16 cents	1927—15 cents
1920—8 cents	1938—7 cents	1923—19 cents	1934—11 cents
1926—9 cents			

In the case of wheat, the purchasing power of a bushel of wheat has also shown marked cyclical changes, greater than the year-to-year changes. The years of low purchasing power of wheat were 1912–13, 1922–23, and 1931–32; roughly a 10-year interval, with prices around 80 cents per bushel (in pre-war purchasing power) in 1912–13, 60 cents in 1922–23, and 35 cents in 1931–32. The years of relatively high wheat prices were 1917, 115 cents; 1925, 95 cents; and 1936, 83 cents. The corresponding cotton and wheat cycles of the past 25 years are not characteristic of previous years.

In the case of hogs and cattle, however, cyclical swings in prices have persisted for many decades. The cattle-price cycles are shown in figure 10 for both milk cows and cattle other than milk cows. Note how the relatively high prices have come at fairly regular intervals of 15 years—1884, 1899, 1915, 1930. The low-price years, however, do not show this regularity. Note also how each succeeding peak in the prices of milk cows exceeds the previous one and how the instability in purchasing power has become greater and greater for each succeeding cycle.

The cycles in hog production and prices, like those of other farm products, have also been greater in recent years than in earlier years. They have come with much greater frequency and with greater variability than the cattle cycles (fig. 11). Since 1860 there have been about 4 complete swings in cattle production and prices, but in the case of hogs there have been 16 price cycles, of which 5 have been relatively short—3 to 4 years in duration—and 11 relatively long—5 to 7 years in duration. The short cycles showed relatively small increases from the low to the high points in the price swings, and the longer cycles showed greater swings. In terms of pre-war purchasing power, the minor hog-price cycles have meant price advances of about $3 per 100 pounds, while the major hog-price cycles have usually shown advances of $4 to $6 per 100 pounds.

These fluctuations in cattle and hog prices are basically traceable to the variations in supply and to some extent to variations in demand or in business conditions. The fluctuations are exclusive of those associated with the rise and fall of the general commodity price level. From the standpoint of farmers' income, the years of low supplies and high prices have been the years of high income. Usually the sales of hogs in high-price years have brought farmers fully 50 percent more gross income than the larger marketings in the low-price years. On the other hand, all those engaged in processing and distribution tend to earn less in years of abnormally low supplies than in years of abnormally large supplies. This is fairly typical of the shifts in the

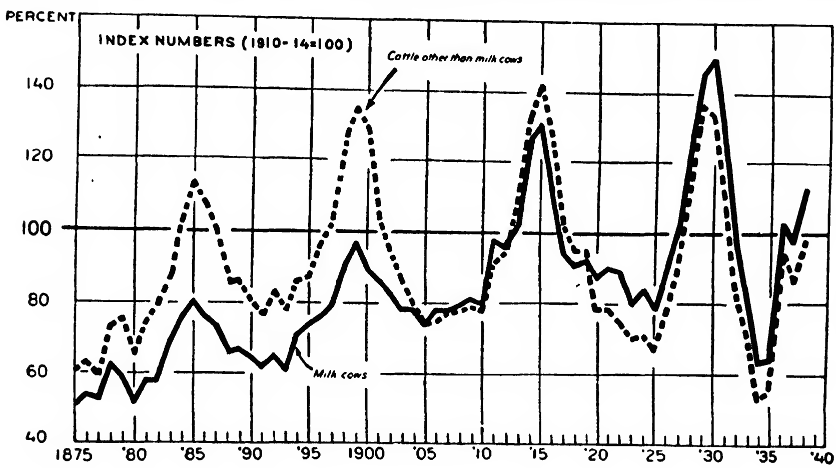

FIGURE 10.—Purchasing power per head of milk cows and cattle other than milk cows, 1875–1937.

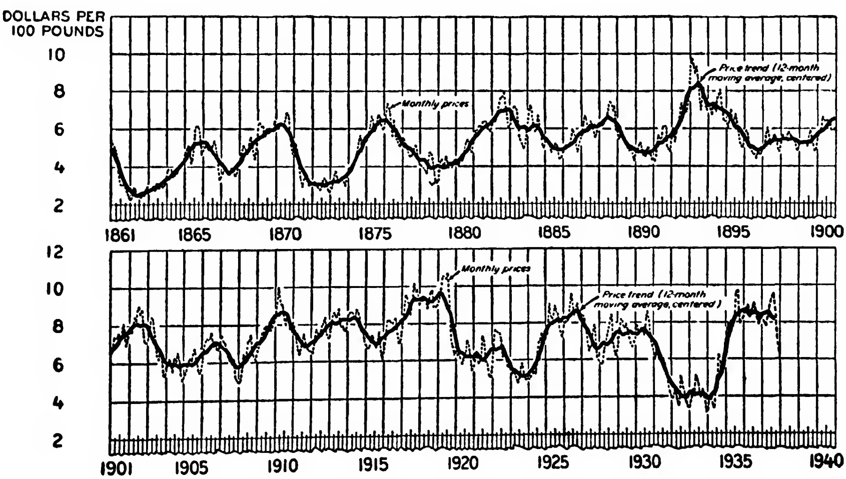

FIGURE 11.—Prices of hogs at Chicago by months, 1861–1937.

short-time advantages of farmers and other groups, and it is partly responsible for the emphasis placed in the 1938 Agricultural Adjustment Act on the desirability of maintaining a more even flow of farm products to domestic markets at more stable prices, with due regard for continuing the export of surplus production. It is not to be expected that the different sections of agriculture can do a better job of managing their soil resources in the future than they have done in the past unless the uncertainties and fluctuations in prices and demand are minimized and income from farming is placed on a more stable basis.

INTERNATIONAL RELATIONS AND NATIONAL MONETARY POLICY

In 1932, Sir Josiah Stamp wrote that one of the root problems of agriculture has been that the world as a whole "has almost certainly been fed below cost price for the last 100 years, if one takes into account the proper elements of cost" (*325, p. 260*).[2] One of these elements is the maintenance of the productive powers of the soil. Although this condition has been due to a variety of factors, general economic instability has in recent years been important among the influences tending to place agriculture in a position such that outlays necessary to maintain soil resources at their optimum cannot ordinarily be met out of income. During the post-war period, international economic relationships and monetary influences have been particularly important factors in general economic instability. Some of the factors in the international economic complex which have adversely affected agricultural land use and some of the aspects of national monetary policy as they bear upon the same problem will here be dealt with briefly. The international factors may be grouped under three broad categories—those traceable to deep-seated influences; those traceable to the World War; and those connected with the economic depression that set in after 1929.

It is hardly possible to do more than mention the deep-seated influences. First among them has been the steady expansion of agricultural output owing to the introduction of greatly improved techniques of production. The adjustment of output to demand, which has always been a crucial problem by reason of the relative inelasticity of demand for agricultural products, has been rendered more difficult by the slowing down of population growth in the Western Hemisphere and by positive declines in the consumption of cereals. Another factor has been economic nationalism, which is best regarded not as a manifestation peculiar to the post-war period, but as a persistent tendency which has been intensified in that period. Contributing to this influence have been the desire for self-sufficiency and the continued spread of the techniques of the industrial revolution, which has somewhat reduced the need for international specialization. Countries that previously relied upon exports of agricultural products to purchase manufactured products have been able to develop a considerable volume of manufacture on their own account. This in turn has created pressure to contract resources devoted to agriculture.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181. Other publications dealing with the same subject but not specifically referred to are: (*47, 67, 68, 72, 75, 84, 97, 101, 122, 126, 135, 141, 143, 199, 203, 211, 212, 246, 273, 283, 309, 326, 327, 343, 364, 426, 447, 463, 472*). In the preparation of this section the following were especially useful: (*67, 122, 126, 135, 203, 273, 283, 325, 327*).

Added to these underlying factors has been the peculiar politico-economic legacy of the World War. The war itself created a profound distortion of the world economy. The belligerent nations shifted their manpower to battle fronts and munition factories. This was accompanied by drastic curtailment of their export trade. These shifts in turn had their effects upon the neutral countries, which had to adjust their economies to the production of goods formerly obtained from the belligerents and to supplying Europe with such food, raw materials, and munitions as could be shipped past the blockades.

The liquidation of this war economy was in itself a major obstacle to the restoration of the pre-war balance, but to this other burdens were added. First were the "economic consequences of the peace," which included the contraction of the German economy, the assessment of reparations, the collection of war debts, and the creation of new groups of rival European states. With these came the intensification of economic nationalism as the new states struggled for national unity and as all nations, shuddering from their wartime experiences, aspired to self-sufficiency. It should be noted that the development of centralized economic controls during the war in conjunction with this new nationalism gave impetus to the idea of continuous economic planning.

Post-War Recovery and Collapse

Despite the difficulties, there was a strong tendency for the world to seek to return to something like its pre-war balance, and the creation of a network of financial arrangements induced a temporary, though abnormal, prosperity. After the slump of 1920 had run its course, there came a revival stimulated by huge private credits to the countries suffering from a shortage of capital, and stimulated also by various inflationary policies such as currency devaluation. An appearance of normality was introduced by the reestablishment of the gold standard and stable exchanges, often with dubious parities, and by agreements with respect to the payment of war debts and reparations. The great streams of credit tended to alleviate underlying maladjustments. They permitted the transfer of debt payments, stimulated capital expansion in the borrowing countries, and allowed the creditor countries to enjoy a lively export trade. This expansion occurred in the face of constantly rising tariff barriers, which were early recognized as being inimical to long-run prosperity in that they tended, among other things, to prevent the free flow of commodities essential to the ultimate settlement of international financial obligations. Against this extreme protectionism the World Economic Conference of 1927 fought in vain. Unsound as these arrangements were for the long run, they did for a time, particularly in the period 1925–29, produce a world-wide prosperity.

Collapse was inevitable. The steady increase of agricultural output brought a condition of maladjustment, clearly evident in some lines from about 1925, into this sector of economic activity. Out of this were born numerous schemes of stabilization and valorization. Among these may be mentioned the stabilization activities of the Federal Farm Board in the United States and, particularly after 1927, Brazil's control of coffee supplies. The volume of manufactured goods

also increased, bringing acute competition in the international markets; while the pressure of debt payments tended to reverse the currents of international trade. As these pressures exerted their depressing influences upon the several national economies, they attempted to shield themselves by new trade restrictions and currency manipulations. In the end, they only intensified and prolonged the slump.

The New York stock-market crash of 1929, the Hoover moratorium, the Credit-Anstalt failure, withdrawals of gold to France, and Great Britain's abandonment of the gold standard are familiar events. Familiar also are the decline in world output and trade, the fall of prices, unbalanced budgets, currency depreciation, rigid control of international trade, and unemployment.

Certain general influences exerted by the depression call for special attention. It accentuated the characteristic difficulties of agriculture in adjusting itself to conditions of oversupply and reduced urban purchasing power. While industry quickly contracted output, discharged workers, and maintained prices, agriculture continued to produce at peak levels, accumulated great surpluses, received ridiculously low prices, and lived on reduced incomes.

In the world at large, the desire to buttress national economies against international collapse accentuated the drift toward self-sufficiency, while the idea of national economic planning received fresh impetus and became the topic of widespread debate. This debate is still in full swing. The issues involved are of the greatest importance and have received almost universal attention. It is noteworthy that the discussion has extended beyond statesmen, professional economists, and government administrators to include the man in the factory and on the farm. There are signs that the outcome will be a clearer perception of the social and economic problems confronting the Nation, and general agreement as to the role which the Government will play in their solution.

Although many forces beyond our control have contributed to placing American agricultural producers in an unfavorable position, it is necessary to note that certain post-war policies of the United States added to the difficulties. To begin with, the United States lent great sums of money abroad. Many of these loans were justifiable as investments and as measures of general economic reconstruction; but many went into unsound ventures and to debtors whose powers of repayment were doubtful. As a result of this lending, the shift of the United States from a debtor nation to a creditor nation, which began during the war, was accentuated. In the normal course of events, this shift in financial status would have led to an excess of imports over exports as the debtor nations made their repayments, but at this juncture the United States failed to realize that it needed to moderate rather than to intensify its traditional tariff policy if it was to deal successfully with the situation created by its new international financial position. Although eager to collect what was owed us, we imposed formidable barriers to collection by the maintenance of high tariffs. This made it difficult for the debtor nations to send into this country the commodities that constituted their means of payment. The difficulty, however, was temporarily obscured by the great excess of loans over repayments. The foreign debtors were able to use the

borrowed money, though indirectly, not only to meet their obligations to the United States, but also to buy large quantities of American goods. But when the depression stopped this stream of credit, the debtors found it difficult or impossible to do either.

To sum up, American agriculture, which was beginning to adjust itself to a gradual contraction of its foreign markets during the pre-war years, suddenly found itself with a greatly overexpanded plant called into being by the abnormal demand of the war years. Drastic readjustment was an obvious necessity, but the process was delayed by the international financial arrangements and credit policies of the post-war period. In the end, however, the pressure of competing supplies on the one hand and the narrowing of international markets on the other forced the issue. The process of adjustment was made particularly severe by the sudden cessation of foreign lending on the part of the United States and by the general price collapse accompanying the cyclical downswing which set in after 1929.

These international developments carry certain implications for American agriculture. On the one hand, the agricultural output of the United States must be adjusted to losses in foreign markets, if producers of export crops are to obtain returns which will enable them to cover normal costs, including the cost of maintaining soil fertility. Without this adjustment, farmers will continue to produce a total output which can be disposed of only at prices inconsistent with soil conservation and good farm management. To the extent that the maintenance of foreign outlets is dependent upon such prices, the United States is in the position of conducting a perpetual bargain sale in farm products at the expense of vital soil resources. During the period of adjustment, it will probably be necessary to supplement the income of farmers by conditional grants of money in order to secure full maintenance of soil resources. On the other hand, the loss of markets does not imply that the United States must completely abandon its foreign markets for agricultural products. The mutual advantages of international exchange are still very great. Furthermore, there is a growing realization that trade barriers and policies of self-sufficiency have overshot the mark. The reciprocal trade agreements program of the United States, for example, constitutes an important step toward a general adoption of more rational policies of international trade.

Agriculture and Economic Instability

Up to this point, the influences affecting agriculture have been viewed as a series of historical events occurring in the international sphere. It is necessary to examine separately the alternating periods of prosperity and depression known as the business cycle. Although this phenomenon has long occupied the attention of economists and has given rise to numerous proposals for leveling out the peaks and hollows of prosperity and depression, it was the experiences of the last depression that brought the problem most clearly into focus and created an insistent demand that governments evolve policies that will bring some measure of stability and security.

It must be emphasized that the problem of the business cycle is an unsolved one. Economists are still groping toward a solution, and

their efforts have given rise to a host of theories—some complementary, some competing. Until the causal factors are more clearly established than they are today, measures taken in the hope of substantially modifying the cyclical movements can at best be only partially successful. Nevertheless, the numerous and painstaking investigations into the nature and causes of the cycle have resulted in an increased understanding of the problem and point the way toward the development of more adequate methods of control.

Some of the more significant aspects of the cycle and some of the more promising possibilities of control are within the sphere of monetary policy.

An adequate monetary policy involves an integration of government fiscal policies with those of the banking system. In this country, banking policies mean primarily those pursued by the Federal Reserve System, which exercises a considerable influence upon the supply of bank credit and upon interest rates. Government fiscal policy includes policies of taxation and spending, which in turn give rise to a number of problems, including that of deficit financing.

It is beyond the scope of this paper to develop any theory of monetary control or to recommend changes in the Federal Reserve System with respect to either its structure or its policies. It is, however, pertinent to note that central banking operations must become more effective than they are at present if a reasonable degree of stability in the economic system is to be secured. It is the opinion of a substantial number of economists that increased effectiveness involves a more complete control by the central banks over the supplies of credit and their acceptance of the stabilization of economic activity as the primary objective of their operations. Ways and means, however, are currently the subject of controversy. With respect to increasing central bank control over the supply of bank money, opinion in the United States ranges from the moderate proposal requiring that all banks become members of the Federal Reserve System to that of taking from the individual banks their present powers of expansion and vesting control of the total volume of credit with the central banking authority. With respect to the criteria by which to guide a general policy of stabilization of economic activity, opinions are divided. The criteria proposed include stabilization of the wholesale price level, stabilization of total money income, and maintenance of neutral money, which means that money is to be so regulated as to be a passive factor in economic activity in the sense that price changes are to reflect changes in the supply and cost of goods and not changes in the supply and velocity of money.

Despite the present state of uncertainty, it is reasonable to expect that with increase in knowledge of the factors underlying the business cycle, with the development of monetary theory, and with the accumulation of central banking experience, the banking system will come more and more to exert a strong positive influence in the direction of economic stability.

Some Problems in Cycle Control

The extreme fluctuations in the output of durable goods which characterize the cycle create special monetary problems and have

been primarily responsible for the suggestion that the volume and character of Government spending be so adjusted as to mitigate them.

In the modern economy, the expansion of durable goods is accompanied by an increase in the output of semidurable and nondurable goods, and boom periods are characterized not only by a growth of capital, but by a rise in the general standard of living. Unfortunately the joint expansion of capital goods and consumption goods comes to an abrupt end and is followed by a long period of depression. The precise mechanism of the stoppage and the ensuing slump is obscure. To many, however, a basic source of difficulty appears to lie in the fact that the rate of expansion in durable goods outruns the rate of expansion in semidurable and nondurable goods and that the existing economic mechanism is defective in that the shift from durable to nondurable goods necessary to equalize their rates of expansion fails to take place automatically.

Earlier cycle theories viewed depressions as little more than general gluts of commodities from which recovery would be automatic and relatively swift. Prices, including wages, would fall to levels that would bring liquidation of excess stocks and revive the demand for labor. Enterprise would soon become profitable and expansion would follow. Although it is true that if contraction continues long enough, the cumulative effect of such things as the eventual slowing up of the general price decline, falling costs, and replacement demand will tend to generate expansion, the policy of letting nature take its course usually results in a contraction out of all proportion to the liquidation required to eliminate maladjustments which developed during the boom. In the modern economy, various rigidities prevent the price mechanism from effecting the desired adjustments within a reasonable time and at a reasonable cost. Instead of a quick readjustment, the downturn is followed by excessive contraction of output, large unemployment, hoarding by investors and consumers, and complete loss of confidence. The depression tends to become chronic, and rapid recovery does not take place without strong stimuli such as widespread introduction of cost-reducing techniques, the development of important new products, or deliberate Government policies which create incentives to investment on a large scale.

Insofar as this type of analysis is valid, it creates a presumption in favor of governmental fiscal policies which will tend to increase consumption relative to investment during boom periods and increase both consumption expenditure and investment during depressions. Business-cycle history indicates that either increased investment or increased consumption may lead in a recovery.

Public Works

The attention of economists has been centered primarily upon policies to be followed in depressions. The policy which has received the greatest support is that of governmental expansion of public works to stimulate the production of durable goods and the revival of investment. Although the basic arguments for this policy have never been successfully challenged, the effective operation of a works program involves moot problems of financing and of the timing of expan-

sion and contraction of expenditures. The latter question, though crucial, is too involved to be dealt with here.

With respect to financing, it is obvious that depression spending must be financed either out of accumulated reserves or by borrowing. It may be noted in passing that a policy of accumulating reserves involves difficult problems, particularly with respect to the conversion of reserves into cash during a depression. Insofar as depression spending is financed by borrowing, it is implied that the national budget will be unbalanced during the depression and that loans will be repaid out of taxes collected in the succeeding period of prosperity. With respect to the vexing question of balancing the budget, it is obvious to everyone that in the long run income must equal outgo. The real issue is whether the budget is to be balanced every 365 days, or whether deficit financing in depression followed by repayment during prosperity be adopted. Acceptance of a policy of compensatory Government spending involves the latter. The emphasis here placed upon public works does not imply that Government spending during a depression should be confined to this particular type of activity. Many of the ordinary functions of government may well be expanded, and the expenditure of funds for relief will always be necessary when unemployment becomes large and prolonged. The ability of the Government to concentrate its spending in crucial periods will depend upon the development of budgetary machinery, currently termed the flexible budget, which will provide that adequate funds be available when needed and that a program of public works and other useful Government projects be drawn up in anticipation of depression needs.

Fiscal policies in prosperity have not received the detailed attention accorded to fiscal policies in depression. However, if the theory of effecting shifts from investment to consumption expenditure during the prosperity phase is valid, this implies that Government spending policy during prosperity should favor outlays that will result primarily in the purchase of consumption goods, and that taxation policies should favor taxes that tend to reduce savings as against those that tend to reduce consumption expenditure. The aim here would be not so much to tax funds away from investors into the Treasury as to cause them to divert their expenditures into consumption. In this connection, the problem of timing reappears. Efforts to check investment must be made at a time when it threatens to become excessive, but not at a time when desirable investment and full recovery will be retarded. Furthermore, the effects of the repayment of Government debts contracted during depression to bondholders during prosperity have never been adequately explored.

Although the development of monetary policy holds definite promise with respect to the stabilization of business activity, it cannot at this stage be turned to with great confidence. With special reference to Government fiscal policies, it needs to be pointed out that in order for them to become truly effective as a stabilizing force, there must develop a strong public and legislative attitude in favor of debt reduction in periods following deficit financing; a complete overhauling of the Nation's tax structure, Federal, State, and local, with particular attention being paid to the relations between the tax structure and economic stability; an integration of the taxation and spending policies

of the various taxing units; and the perfection of the technique of the flexible budget as a means of making shifts in spending policies in time to be effective. Of the utmost importance is the development of effective cooperation between Government and business, to the end that the latter will come to regard Government spending as a constructive measure designed to encourage the re-expansion of private enterprise and not as something "unsound" to be taken as a signal for further contraction.

THE NATURE OF COMPETITION IN AGRICULTURE AND INDUSTRY

The relation between agricultural and industrial production and between agricultural and industrial prices has as much impact on soil

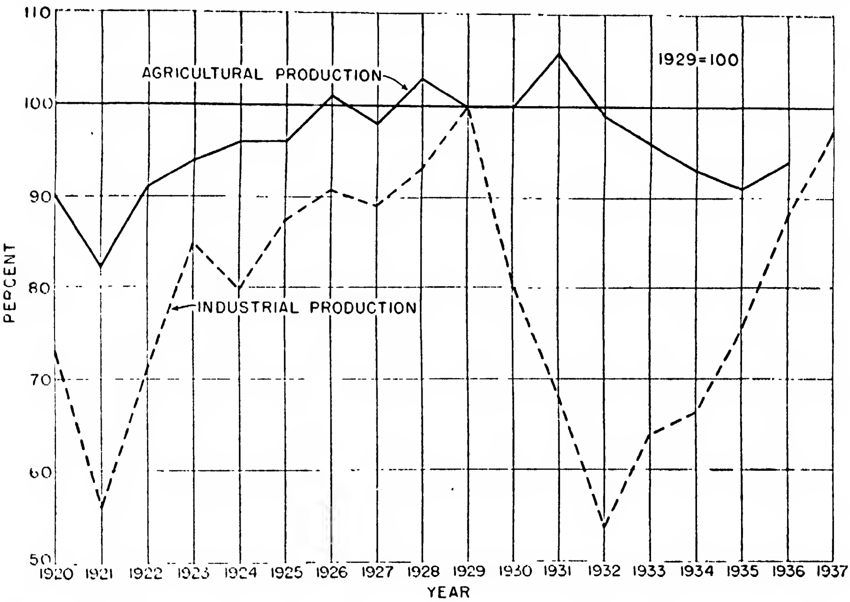

FIGURE 12.—Agricultural and industrial production, United States, 1920–37.

policy as problems within agriculture itself. If industry and agriculture get out of line with each other, neither can make effective use of the resources at its command.

Recent years of depression have shown how far out of line agricultural and industrial production can get. Figure 12 shows the volume of agricultural production and the volume of industrial production since 1920. The dotted line represents agricultural production and shows how steadily, on the whole, farmers have maintained their production through boom and depression, feeding the country, providing the raw materials for clothing, and supplying a surplus with which to buy foreign goods. The dash line represents industrial production. Industry maintained a high and increasing level of production through 1929, but then began to limit its production until by 1932 it was producing little more than one-half as much as in 1929. In 1932,

the farmers supplied the rest of the population with as much farm produce as before the depression, but farmers received from industry only 55 percent as much fertilizer, only 25 percent as much agricultural equipment, and only 10 percent as many new passenger automobiles as in 1929. Thus, the farm side of the team was pulling as hard as ever, but the industrial side was not pulling its share, and the whole producing team was out of balance.

At first thought it might look as though the farmers were the only group harmed by this unbalance, since they were swapping the same amount of farm products for a smaller amount of industrial products. Actually, the unbalance between agricultural and industrial produc-

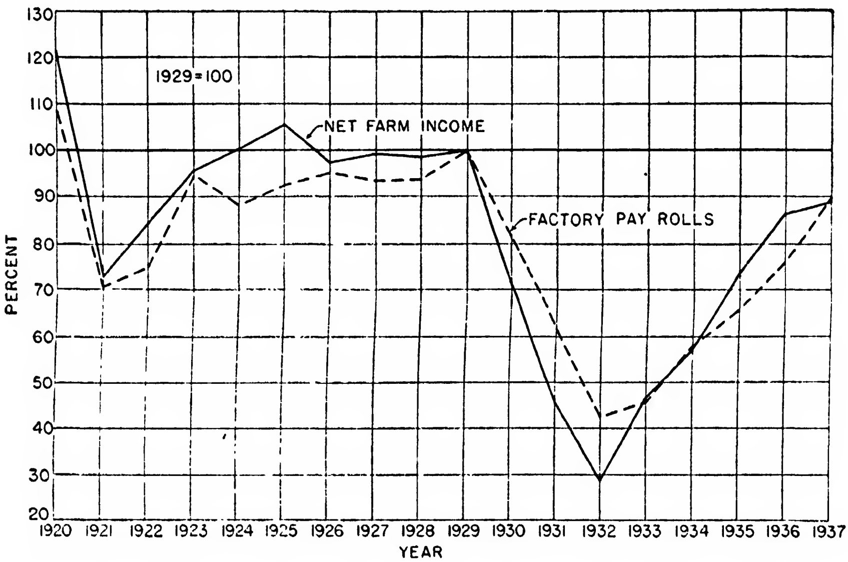

FIGURE 13.—Factory pay rolls and net farm income, United States, 1920–37.

tion that developed after 1929 was just as hard on the industrial worker as on the farmer. This is shown very clearly in figure 13. This time the dotted line represents the net farm income of all farmers since 1920, while the dash line represents the cash income or wages received by factory workers. It is evident from the chart that the unbalance in production involved just as much of a drop in the income of industrial workers as it did in farm income. Neither group was getting the better of the other so far as income was concerned.

Though the unbalance between agricultural and industrial production involved an equal drop in the income of farmers and industrial workers, the depression loss of income in the two cases came about in quite a different manner. Farm income declined primarily because of the drop in farm prices. Farmers worked just as hard as ever, but the lower prices brought in less income. With the industrial workers most of the decline in income came from being unable to find jobs or being allowed to work only part time; only part of the decline of income came from lower wage rates. Unemployment cut into the

industrial workers' income in the same way that falling farm prices cut into the farmers' income. The parallel between falling farm prices and falling industrial employment is shown in figure 14, which indicates the decline of farm prices by the dotted line and the decline of industrial employment by the dash line. A third line representing the decline of industrial profits is included to indicate that the decline in the income of farmers and industrial workers did not mean more profits to the owners of industry. All three groups were in the same boat and suffered because of the depression-induced unbalance between agricultural and industrial production. It should be noted, however, that the generally lower level of the profits line in this chart

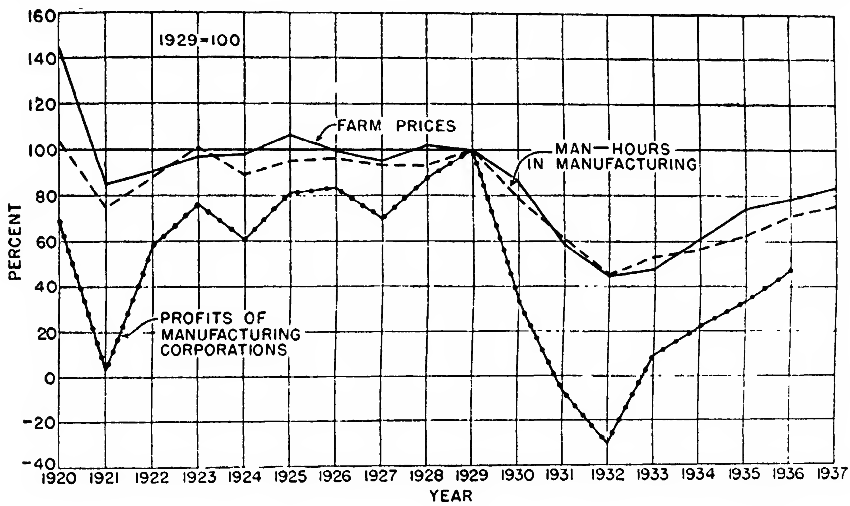

FIGURE 14.—Net profits of manufacturing corporations, man-hours in manufacturing, and farm prices, United States, 1920–37.

is due to the fact that profits were abnormally high in 1929, the year arbitrarily designated as 100.

By 1932, the hardships due to the unbalance between agricultural and industrial production (and to other causes) were so great that agriculture, labor, and industry combined in seeking a way out. Here was agriculture maintaining its steady pace of production, and industry backing down on the traces. Harder pulling, that is, more production, by agriculture could only make the unbalance worse. The first step adopted was an emergency one of easing up on the agricultural side of production and at the same time prodding industry into greater activity. Agricultural production was curtailed and industrial production was increased until each side of the producing team was pulling with more nearly equal weight, though neither was pulling at its full capacity. Once the two sides of the team were pulling equally, the problem became one of stepping up both agricultural and industrial production until both were producing to the full.

In stepping up agricultural and industrial production together it was essential that neither get ahead of the other. Since the farmers

were ready to produce at capacity but the managers of industry were unwilling or unable to hire the workers to keep industry operating full time, a program to maintain balance between the two required a continued prodding of industry to increase production and a continued control of agricultural production—a control that could be gradually relaxed as industrial production increased. Actually, through the action of the courts, most of the restraining influence on agricultural production in 1936 and 1937 was removed and farm production pushed way ahead of industrial production, throwing the team out of balance again, while in the latter part of 1937 industry again started to slack off on production. Thus unbalance between industrial and agricultural production remains a basic problem—one of the most important problems of the day.

This unbalance between agriculture and industry arises primarily from the difference in the organization of these two fields of activity and the effect of this difference on price and production policy. The bulk of agriculture is carried on by individual farmers with at most a few hired workers or sharecroppers. The bulk of industry is carried on by big corporations. In 1929 over 49 percent of the assets of nonfinancial corporations were controlled by 200 huge enterprises—railroads, utilities, manufacturing enterprises, distributing enterprises, and a few enterprises supplying services. By 1933 this concentration had markedly increased, something like 56 percent of the assets of nonfinancial corporations being in the control of 200 companies. While these figures apply only to that proportion of the national economy that is carried on by corporations, the big corporations constitute a very important element in the national economy. Something like a quarter of the wealth of the country must be in their hands.

Such economic concentration means that, in one industry after another, a few large, highly organized corporations dominate the market for industrial products in contrast to the millions of separate farmers who compete with each other in supplying the markets for farm products. Many examples of this dominance arise in the industries with which farmers are concerned. For industries from which farmers buy, 64 percent of the agricultural-implement industry, as measured by employment, was in the hands of four companies; 63 percent of the motor-vehicle industry was in the hands of three companies; 62 percent of the rubber-tire industry, 32 percent of petroleum refining, and 25 percent of the fertilizer industry were in each case in the hands of three companies. Likewise, for industries which process farm products and supply materials for use in processing, 99 percent of cigarette making, measured by employment, was in the hands of four companies; 63 percent of tin-can manufacture was in the hands of three companies, 44 percent of meat packing for wholesale, 44 percent of condensed- and evaporated-milk manufacture, one-third of cottonseed-oil cake and meal manufacture, nearly one-third of poultry killing, 27 percent of sausage making, and 24 percent of cheese making were each in the hands of four companies. Thus the farmer deals with big business in things he needs to buy to operate his farm and is likely to be dealing again with big business when he sells his farm products. Again he is likely to come in contact with big

corporations when he ships by rail, seeks electric power on the farm, or requires farm financing. The whole function of farming is performed in an economy a large part of which is dominated by big business.

This corporate concentration has long been recognized and has given rise to much discussion of monopoly profits. In the early days, monopoly profits were discussed in connection with the granting of corporate charters. At every period since there has been discussion of monopoly profits—at the time of the Granger movement, which culminated in railroad legislation, and of the Populist movement, which was in part reflected in the Sherman Anti-Trust Act; during the "trust-busting" activity after 1900; and in the cry against monopoly profits today.

But in very recent years monopoly profits as such do not appear to have been a factor of major significance. From 1931 to 1934 the big corporations were making little profit and many were suffering great losses. Yet in these years the farmers were receiving the lowest incomes of recent record. Undoubtedly the existing corporate concentration has resulted in some monopoly profits, but its more important effects are of a different character.

The most significant result of present-day concentration so far as the farmer is concerned appears to be its effect on the production and price policies of industry. Though concentration has not in recent years involved large monopoly profits, it has gone to such a point that, in industry after industry, production is controlled and prices are relatively inflexible. In a great many industries the number of concerns directly competing with each other is so small that the individual concern can adopt a price policy limiting its production to the demand for its product at the prices adopted. While each concern may have only a narrow margin within which it can choose one price rather than another and still make profitable sales, each concern is likely to have an interest in keeping its prices constant. The net effect of this action by each of the few concerns in an industry is to make prices in an industry relatively inflexible. Though many industrial prices have always shown inflexibility, the increasing industrialization of the country and the concentration in particular industries have greatly increased the role of inflexible prices.

This inflexibility of prices reflects primarily a lack of sensitivity to changes in consumer buying power. Where there is sufficient competition in a concentrated industry to prevent appreciable monopoly profits, prices are likely to fall gradually with improving technology or change gradually with changes in the cost of the product. Prices will thus show a long-run flexibility. But in such an industry competition may not be sufficient to make prices sensitive to short-run changes in consumer buying power. A fall in buying power and the corresponding fall in the demand for the products of the industry does not result in a lowering of prices but rather in a curtailment of production, reduced employment, and less buying power paid out in the form of wages or made as profits. A concentrated industry thus reacts to a fall in consumer buying power in such a way as further to decrease the power of wage earners to buy both industrial and farm products. Where prices are kept inflexible for periods of time and production is controlled to meet the demand at such prices, any

initial decline in consumer buying power tends to be multiplied and made more serious rather than corrected.

This is in sharp contrast to the reaction of agricultural prices and production to a decline in consumer buying power. The individual wheat farmer has no control over the price of wheat. He produces and puts the product on the market for what it will bring. When the current buying power of consumers falls off, farmers as a group continue to produce about as much wheat as before, and competition between the millions of wheat farmers sends the price of wheat down

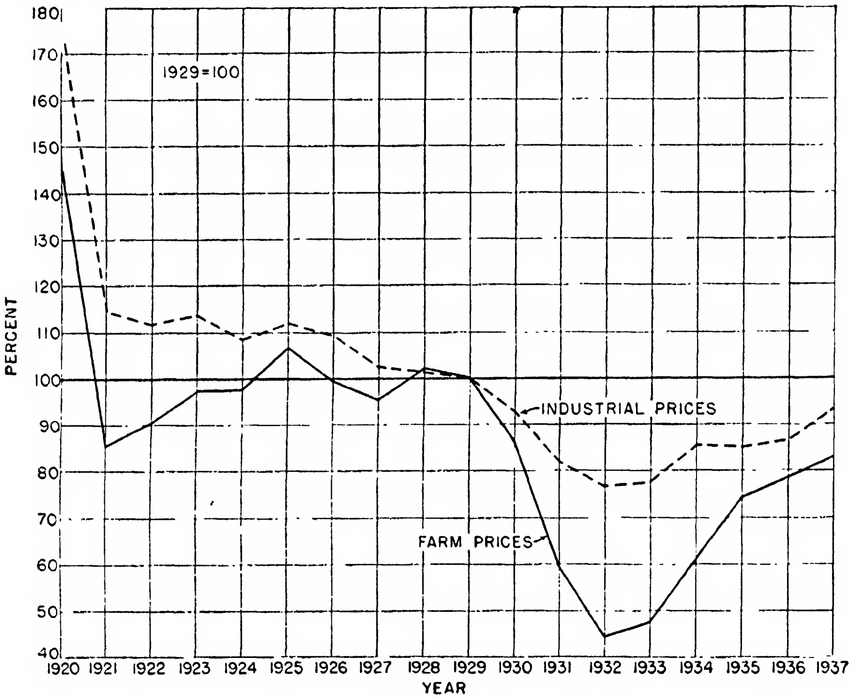

FIGURE 15.—Agricultural and industrial prices, United States, 1920–37.

in response to the reduced demand for wheat at the old price and level of buying power. The money income of the farmer is reduced, but the real buying power of all consumers is increased by the lower cost of wheat. Thus the high degree of competition among farmers and the resulting flexibility of farm prices act in a direction to correct any initial reduction in buying power rather than to exaggerate it.

If all industries were as highly competitive as most of agriculture, any variations in consumer buying power or consumer expenditure would be quickly adjusted by changes in price. But where a large part of industry is concentrated and prices become inflexible, while other parts of industry and agriculture are highly competitive with flexible prices, variations in consumer buying power become highly disorganizing and produce the unbalance between agricultural and industrial production already shown in figure 12 and the corresponding unbalance in prices shown in figure 15.

If it were possible to change the structure of industry so that each industry was carried on by thousands of separate and competing enterprises, it might be possible to eliminate the power of industries to control production and hold prices inflexible. By such a drastic break-up of industry into very small units, all prices might be made as flexible as most agricultural prices and the disorganizing influence of production control and inflexible administered prices might be eliminated. But concentration, production control, and inflexible prices appear to be inherent in the organization and techniques of modern industry. If the advantages of mass production are to be kept, production control and inflexible administered prices in industry are with us to stay.

Up to this time little thought except of an emergency character has been devoted to the discovery of ways to make the controlled production and inflexible prices of big corporate enterprise compatible with a free market system for agriculture and with effective use of national resources. As an emergency measure, restriction of agricultural production was made necessary by the extensive restriction of industrial production. As a matter of long-run policy in the use of soil, a balance between agriculture and industry must be sought in expanded industrial output, not contracted farm production. Yet until the market for farm products is fully rebuilt by full employment in industry, unrestricted agricultural production is likely to burden the farmer without a compensating gain to other groups and lead to ineffective use of the soil.

From the point of view of the farmer, the problem of farm income and of effective use of soil is thus essentially the same as the problem of jobs and income for the industrial worker. Both are dependent on the full-time functioning of industry, as are the profits of investors. And the heart of the problem of agricultural and industrial balance at a high level of production lies in the characteristics of concentrated industry—not in monopoly profits but in the control of production and inflexibility of prices to which concentration gives rise. Until the unstabilizing tendencies of concentrated industry are overcome or counterbalanced, a program of effective use of soil can be geared only to an ineffective use of industrial resources and to an inadequate farm income.

FOREMOST *among the means for bringing about widespread soil conservation in this country are research and education. Research is needed to determine the relative advantage of various soil types for particular purposes, and the relative advantage of different practices on the same soil type. Among other things, this leads to land classification and intelligent land-use planning. The Extension Service, whose local resident agents form a connecting link between farm people and the research institutions, is a major influence in spreading the use of sound practices. Soil conservation demonstrations make them concrete and vivid. All of these are dealt with in this article. Beyond them there are the schools, the press, the radio, which must help in the educational process, especially in areas where there has been soil wastage for generations. In these areas there will have to be a fundamental change in the attitudes of people on the land if permanent settlement is to be possible.*

The Remedies: Education and Research

By C. W. Warburton, C. B. Manifold, Charles E. Kellogg, *and* C. P. Barnes [1]

EXTENSION WORK IN SOILS

SUCCESS in farming depends in large measure on wise land use, with adjustments to meet changing economic conditions. Each farmer must plan the operations on his own farm. The major purpose of research in agriculture is to discover means and principles to aid farmers in meeting their problems. The applications of the results of research must, however, be made by the farmers. In the closing years of the nineteenth century and the first decade of the present one, the Department of Agriculture and the State experiment stations had accumulated a great mass of research information, much of which had not been put into general use by farmers. The Extension Service was established to provide a means of making research information readily available to those on the land and to assist farm people to use it in solving their individual problems. Trained exten-

[1] The section headed Extension Work in Soils is by C. W. Warburton, Director, Extension Service. The section headed Soil Conservation Demonstration is by C. B. Manifold, Chief, Division of Conservation Operations, Soil Conservation Service. The section headed Soil Survey and Research is by Charles E. Kellogg, Principal Soil Scientist, Bureau of Chemistry and Soils, and the section headed Land-Use Planning and Land Classification is by C. P. Barnes, in charge, Survey Coordination, Office of Land Use Coordination.

sion agents resident in the counties are informed on local conditions and in touch with sources of research information, thus forming a connecting link between farm people on the one hand and the research agencies—the State experiment stations and the Department of Agriculture—on the other.

The extension program in a county is largely determined by the people of the county. Representative farmers and farm women from the different communities in the county meet with the county agents early in the year, decide what their most important farm and home problems are, and, with the advice and assistance of the county agents, work out an extension program designed to meet them. Frequently, a county agent supervisor or subject-matter specialist from the State agricultural college participates in the conference and presents information that bears on the problem from the experiment station or the Department. When ways of meeting the problem have been agreed on, arrangements are made with farmers or farm women in different sections of the county to demonstrate these methods on their own farms or in their own homes for the benefit of themselves and their neighbors.

The demonstration method is an essential part of extension work. When the cotton boll weevil threatened the cotton industry of the South early in the present century, Seaman A. Knapp, representing the Department of Agriculture, established practical farm demonstrations of ways of combating it. These demonstrations were conducted by the farmers under the supervision of itinerant agents employed and directed by Dr. Knapp. This method of meeting farm problems soon spread to other sections of the country; the itinerant agent was replaced by an extension agent resident in the county. By the passage of the Smith-Lever Act in 1914, the system was made nation-wide.

While the demonstration is still an important and essential part of extension work, extension agents use a wide variety of teaching methods. Bulletins, news articles in local newspapers, motion pictures, radio talks, exhibits, talks at meetings, discussion groups, and many other means of presenting information are included in the program of the county extension agent.

The Extension Service is financed jointly by the Federal and State Governments, with headquarters at the agricultural college in each State. The employment of county extension agents is usually cooperative, so that the county extension agent is jointly employed by and represents the Federal Government, the State, and the county. To supplement the work of the county agents and assist them on special problems, each State employs a staff of subject-matter specialists, in such fields as animal husbandry, agricultural economics, horticulture, and crops and soils.

In most State colleges of agriculture, the soil is considered primarily as a medium in which to grow crops, and educational and research work in soils and crops are conducted by the same staff members, frequently designated as agronomists. State extension specialists in agronomy, most of whom devote at least a part of their time to extension work in soils, now number 101 full-time and 51 part-time workers. In the past 2 years, many of the State extension services have entered

into cooperative agreements with the Soil Conservation Service, employing jointly a specialist in soil conservation whose function is to coordinate the activities of the two agencies in this field.

Some Examples of Extension Work in Soil Improvement

From the beginning of extension work, the importance of the soil as a basic agricultural resource has been recognized, and soil conservation and improvement have been an essential feature of the extension program. Extension work in soils can best be discussed by giving a few specific examples of what has been done to meet soil problems.

Southern research workers, over 40 years ago, recognized the heavy losses from soil erosion and leaching from unprotected land during the winter months. Experimental work in Alabama indicated the value of a winter-legume cover crop as a remedy. In 1918, the Alabama Extension Service was instrumental in getting farmers to plant about a ton of winter-legume seed on demonstration fields. The results of these demonstrations were so favorable that the planting of winter legumes was made a widespread extension project in the State. Farmers who saw these local demonstrations adopted the practice on their own farms, and the planting of winter legumes has steadily increased. In 1936 nearly 4,100 tons, or more than 8,000,000 pounds, of winter-legume seed were planted in Alabama alone, and a much larger quantity would have been used if seed had been available. Through soil conservation, reduced fertilizer costs, and increased yields of succeeding crops, it is estimated that the income of Alabama farmers has been increased by $36,000,000 from this project since 1918.

A winter-legume campaign in a county, as outlined by the extension agronomist, consists of the following steps:

1. Publish articles in local newspapers in June, reporting what has been done with winter legumes in the county and their further possibilities.
2. Hold meeting of community leaders in June and organize winter-legume committee.
3. Conduct advertising campaign in local newspapers and through use of posters, stickers, and signs on demonstrations.
4. Publish news articles in newspapers during July, August, and September, reporting experiment station and local demonstration results and giving planting directions.
5. Send circular letters on winter legumes to farmers in county.
6. Hold local meetings, tours, and demonstrations.
7. Make exhibits of winter legumes in courthouse, banks, and store windows.
8. Arrange winter-legume programs at luncheon clubs, with farmer speakers.
9. Hold county-wide meetings at experimental or demonstration farms, where winter legumes are discussed.
10. Keep list of farmers planning to plant winter legumes and number of pounds of seed they will require. Assist them to locate seed.
11. Discuss winter legumes at at least one meeting of each 4–H Club.
12. See that every farmer planting winter legumes has proper instructions for inoculation and planting.

The extension agronomist in Louisiana reports that the winter-legume acreage in that State increased from 125,000 acres in 1935 to 200,000 in 1936, and that average increases of 300 pounds of seed cotton, 18 bushels of corn, and 5 tons of sugarcane per acre have been obtained in that State following the growing of winter legumes. Similarly favorable results have been obtained in other Southern States.

For the past several years, the Missouri Extension Service has been conducting a clover-and-prosperity campaign in that State, advocating the more general use of clover and other legumes for soil improvement and for livestock feeding. In 1936, clover-and-prosperity conferences were held in each of the 114 counties in the State. At each of these county meetings, a crops or soils specialist discussed the growing of legumes and their effect on soils, and an animal husbandry or dairy specialist discussed the value of legumes for feeding livestock. Several weeks before these county meetings were held, the campaign was discussed and planned at meetings of specialists and county agents. Wide advance publicity was given the county meetings. The demonstrations conducted by farmers were planned to provide (1) the maximum number of days of good pasture for livestock; (2) the maximum quantity of good legume roughage; and (3) the most efficient cropping system from the standpoints of soil conservation and the production of concentrates to supplement pasture and forage. Farmers have largely increased legume acreages in the State as a result of these demonstrations.

Much of the extension work in soils in the Northeastern, East Central, and Southeastern States has been with a view to assisting farmers to improve their practices in the use of fertilizer by selection of the proper fertilizer for specific soils and crops, the conducting of fertilizer and lime demonstrations, development of local sources of lime, and the making of quick soil tests. In 1936, the agronomy specialist in Illinois supplied county agents with a series of soils charts which were used by the agents in 1,900 meetings attended by more than 60,000 farmers. Quick soil tests developed by several of the State experiment stations were widely used by county agents and specialists in determining needs for phosphorus, potash, and lime. In Indiana, over 3,000 such tests were made at 65 soil-testing clinics, the farmers bringing samples of soil to the meeting from their own fields. Following these meetings, 23,000 samples were tested by county agents and many more by vocational teachers.

The development, on a community basis, of cooperative programs among farmers for soil conservation and improvement is a logical outcome of the extension technique. In turn, these farmer groups cooperate with the appropriate State and Federal agencies for technical assistance where such assistance may be helpful. One interesting and significant example of this development is the organization of several thousand community test-demonstration farms, especially in the Tennessee Valley States. In this instance, the general procedure is somewhat as follows:

1. Appraisal of the agricultural situation in the community by the farm people out of their own experience, at a meeting called by the county agent.
2. Analysis of the important problems affecting the local situation.
3. Development of a program of adjusted farm practices designed to improve the local situation through attack on the problems analyzed.
4. Selection by a committee of farmers of an individual farm in the community typical as to size, character of soil, type of farming, etc., on which the adjusted program is tested.
5. Obtaining the materials needed to carry out the program on this farm.
6. Applying the program on the selected demonstration farm and keeping careful records of the results to guide future practices in the community.

7. Holding meetings of the community group from time to time on the farm to note results and discuss their application.

The owner of the farm, with the aid of the community committee, the county agent, and others whose cooperation may be enlisted, maps the soils and fields on the farm, inventories its facilities and equipment, and determines the changes necessary to conform to the program that has been evolved. The test-demonstration farmer then agrees with his community committee and the State college to carry out this program for a period of 5 years, to keep the necessary records, and to report the results. With certain exceptions, he bears all the increased cost of changes in farm fencing and the purchase of any additional equipment and material needed. He assumes the financial risk involved by shifts in crops and livestock and fertilizer practices. He does this as a service to his community.

Phosphorus is generally one of the more important, if not the most important limiting element in economical crop and animal production and in soil improvement and maintenance. In its experimental work with new processes and new products, the Tennessee Valley Authority has developed highly concentrated phosphatic fertilizers. In keeping with its authorization it is required to have these materials tested on a broad scale. In this relationship, the Authority has been an essential cooperating agency in these test demonstrations, particularly in aiding local groups to obtain materials for the conduct of the farm demonstrations. The need for phosphatic fertilizer for use in these soil-improvement demonstrations and the need of the Tennessee Valley Authority for broad-scale practical testing of its new products, provided an opportunity for cooperation which aids the colleges, the farm groups, and the Authority to accomplish their purposes.

While the value of these products had been demonstrated experimentally by the research of the cooperating agricultural experiment stations, there was need for prompt determination of their practical value in farm use before commercial production on a large scale was begun. The Tennessee Valley Authority, therefore, offered to furnish sufficient quantities of its new form of phosphatic fertilizer free of charge for use on soil-improving crops, particularly grasses and legumes, to enable the community test-demonstration farms to carry out their programs, provided the cooperating community groups of farmers would pay all transportation and handling costs from the plant at Muscle Shoals. These costs are paid by the individual farmer on whose farm the demonstration is conducted, or in some cases by the community group. Where the local situation requires the addition of calcium, the community group also has arranged to obtain whatever ground limestone or other form of calcium is needed to supply this element.

These test demonstrations supply the intermediate link between the long-time careful research by the agricultural experiment stations in determining the value of the new form of fertilizer and its general use on farms in the development of a sound agricultural economy. These broad-scale practical demonstrations under a wide variety of soil and climatic conditions, with the careful records of results that are kept, justify the cooperation of the Tennessee Valley Authority in the enterprise. As the test-demonstration farms are planned with

soil improvement and erosion control as important items in the objectives, there is further justification within the Tennessee Valley area on the basis of their contribution to the prevention of soil losses and the silting of reservoirs.

Community test demonstrations had been established on 6,533 farms in the Tennessee Valley area up to December 31, 1937, with a total area slightly in excess of 1,100,000 acres. Outside the valley area in the seven Tennessee Valley States there were 3,547 more of these farms, totaling 770,000 acres. In addition, there were 1,018 test-demonstration farms in 10 other States, involving 190,000 acres. The total, therefore, was 11,098 farms involving 2,060,000 acres. Probably no carefully planned and controlled test of a fertilizer material has been conducted before on so large a scale.

The essential feature of these test demonstrations is that they are planned, organized, conducted, and to a large extent financed by the farmers in the community, the Extension Service aiding in providing some leadership in setting up the organization and supervising the record keeping, and the Tennessee Valley Authority making a contribution of materials. Because of the large part taken in the enterprise by the farmers, they are keenly interested in the progress of the demonstrations. This interest is evidenced by the large numbers of farmers who attend meetings on these test-demonstration farms, in some cases every farm in the community being represented. Farmers have an essential part in planning the program, and, as the demonstration is conducted under conditions similar to their own, they recognize that the results are dependable and readily adapt them to their own use.

Extension Work in Soil Erosion-Control

For many years, extension workers, particularly in the Southern States, have advocated terracing as one means of controlling soil erosion, and have assisted farmers in running levels, laying out terraces, and adjusting cropping systems. They have also advocated the planting of trees and grass on the steeper slopes. The older boys in 4-H Clubs in a number of the Southern States have been trained to run levels to lay out terraces.

The county agent in Tallapoosa County, Alabama, realized several years ago that one reason why more farmers did not terrace their farms was that the building of terraces with ordinary farm machinery and power was a slow, laborious job. After the need for power equipment was discussed by the agent at numerous meetings of farmers and business men, the county commissioners were persuaded to buy a tractor and power grader and to employ a crew to operate it in building terraces. The farmers for whom the work was done agreed to pay a rate per acre sufficient to cover the cost of operation and to provide for amortization of the original cost of the equipment. Late in 1935, the Tallapoosa County Soil Conservation Association was formed to take over the operation of this machinery and to promote soil conservation and improvement in the county. The association now owns six tractors and seven terracing machines. At the end of 1936 it was estimated that about 40,000 of the 110,000 acres of cultivated land in the county had been properly terraced with this machinery. The idea

of county or association ownership and operation of power terracing machinery has spread widely, not only in Alabama, but in other Southern States. Local planning and local initiative are meeting the problem.

The extension services in the southern Great Plains States have been especially active in the past 3 years in assisting farmers to control wind erosion in what has been popularly known as the dust bowl. Here, millions of acres of grassland had been plowed in the last 20 years for the production of wheat. Continuous wheat growing, shallow plowing, and a series of extremely dry years in which no crop or weed growth was produced put the surface soil in such condition that severe blowing occurred in 1935 and 1936. Somewhat more favorable conditions in a part of the area and the remedial measures which had been applied greatly reduced the acreage subject to blowing in 1937. In February 1936, Congress provided a fund of $2,000,000 for allotment and payment to the States for emergency wind-erosion control. This fund was administered by the extension services of the five States concerned, and was allotted to farmers through county committees. Allotments were limited to 20 cents an acre to pay the cost of gasoline and oil for the operation of tractors to list the land, where the farm operator had his own equipment, or not to exceed 40 cents an acre where it was necessary to hire the equipment. In the five States, in the spring of 1936, approximately 10,000,000 acres were protected from blowing at a cost of $1,422,000.

As soon as sufficient moisture for germination was available, farmers were encouraged to plant strips of sorghum across their fields and to leave the stalks standing during the succeeding winter, this practice having been found very effective in checking surface blowing. Much of the listing was done on contour. The effectiveness of this method both in checking soil blowing and in conserving whatever precipitation fell in succeeding months is leading to its very general adoption. This emergency procedure in checking soil blowing was clearly recognized as a temporary measure rather than a permanent cure, and the farmers in the region are now working in close cooperation with the State experiment stations and extension services and several bureaus of the Department of Agriculture in the development of a permanent program. Much of the success of the program was due to the interest of the county committees of farmers, which supervised the work locally.

Cooperative relations have been developed very generally between the State extension services and the Soil Conservation Service of the Department in a common attack on the soil-erosion problem. In practically every State, a State soil conservation committee has been set up, consisting of the State coordinator for the Soil Conservation Service, the director of the agricultural experiment station, and the director of extension. As previously noted, in many States a soil conservation specialist has been employed jointly by the Soil Conservation Service and the State extension service.

Since the establishment of the Agricultural Adjustment Administration in 1933, the extension services in the several States have in large measure served as the field force of the A. A. A., especially in informing rural people about the A. A. A. program and conducting educational

work in its furtherance. Following the passage of the Agricultural Conservation and Domestic Allotment Act in 1936, an agricultural conservation program was set up closely in harmony with the long-time teachings of the Extension Service. Research and extension workers in the several States cooperated with State committees of farmers in developing recommendations for soil conservation and improvement practices for which practice payments would be made by the A. A. A. These payments made it possible for many farmers to adopt on their own farms extension recommendations for the use of lime, phosphate, and legumes, and for other soil-improvement practices which they had long recognized as sound, but which they could not previously put into effect because of the expense involved.

Cooperation between the Tennessee Valley Authority and the Extension Service, both within the Tennessee Valley area and outside, has been discussed. There has also been widespread cooperation between the Extension Service and the Farm Security Administration (formerly the Resettlement Administration) in the preparation of farm-management plans for farm families being aided by that agency. These plans naturally stress erosion control and soil improvement.

Local Initiative Needed

The foregoing paragraphs illustrate a few of the many ways in which farmers are meeting soil problems with extension help. If these problems generally are to be solved, not only from the standpoint of present return but in order that our great soil resources may be conserved for the use of future generations, there must be a full understanding on the part of the people as to what constitutes the best land-use practices in their particular locality. The United States has such a wide variety of soil and climatic conditions that no one remedy or formula is generally applicable. There must be a large degree of local planning and decision by the farmers. There is usually no conflict between good soil-conservation practices and good farm management that will bring a satisfactory income return.

To meet these widely varying conditions in soil and climate, local knowledge and local experience are essential. Such problems can best be solved by local groups or associations of farmers, aided by the technical assistance that the Department of Agriculture and the State colleges can offer. Such local associations offer opportunities to farmers to exchange their views, to pool their experiences, and to adapt research findings to their own use. We shall not have soil conservation on a broad scale until the need for it and the ways to obtain it are a part of our public consciousness and proper land-use practices are recognized as an essential of good citizenship.

SOIL CONSERVATION DEMONSTRATIONS

In October 1933, H. H. Bennett was asked to select a number of watersheds, each about 100,000 to 200,000 acres in area, and undertake to establish as far as possible in those areas such types of erosion control and land use as would be effective in materially reducing soil and water losses. It was intended that these watersheds should serve as proving grounds or demonstrations of what might be done to check erosion damage to farm and range lands; to reduce the

load of silt being deposited in streams and reservoirs; and, in addition, to serve as a measure in the control of floods. Later, in April 1935, this activity was transferred to the Department of Agriculture from the Department of the Interior. The original principle of area demonstrations on a watershed basis has been continued, although the size of a demonstration area has been reduced to about 25,000 acres in order to provide for a wider application of the plan to a greater number of sections of the United States in need of such treatment.

Objectives of Soil Conservation Demonstrations

During the past few years a new concept of the need for demonstrations and new principles of application on the land has developed. In the past, demonstrations usually have been applied on a single field or parts of a field in the farm unit, mainly as a means of showing farmers of the community the advantages of a single practice or treatment, such as terracing or the use of fertilizer. But when soil erosion and flood control were recognized as major problems facing the agricultural and other interests of the Nation, a broader field of actual application was required. The factors influencing floods and soil erosion are not confined to farms or parts of farms, but usually extend outward into an area having natural physiographic boundaries, such as a definite watershed or drainage area.

In order to meet the erosion problem adequately on a national scale, the principle of large-size demonstrations was applied. It is intended that these demonstrations should serve three major purposes:

(1) Education of the public. A well-organized and skillfully applied agricultural plan of considerable size would attract wide attention. This would arouse the interest of the community in examining the work and would lead gradually to an appreciation of an existing erosion problem that perhaps previously had been unrecognized. The understanding of the problem would begin with the participating farmer cooperators and gradually spread outward.

(2) Proving of practices. On a demonstration of this type both old and new measures and practices, either singly or in groups, are applied to the land. It is necessary to give these measures of erosion control a fair trial under the natural conditions of actual farming in order to determine their effectiveness and to give an opportunity for further development. The most useful measures are recognized and made available for application by farmers elsewhere.

(3) Training of technicians. It has been found that a man trained primarily in agronomy, engineering, forestry, or any other agricultural specialty is not properly equipped to plan and apply erosion-control measures without considerable actual experience. The demonstration areas are the training grounds for men in agricultural professions to equip them further in the art of planning and directing the varied activities that are a part of a sound soil and water conservation program.

A Typical Demonstration Project

A typical demonstration project may be described as a complete watershed of approximately 25,000 acres, located in a region where erosion is a problem, but neither containing submarginal land nor

representing the most ideal type of land use and agricultural practices. There is adequate rainfall for the development of vegetative control measures and a topography favorable to carrying out satisfactorily the necessary farm practices. The type of farming prevailing in project areas varies with the region.

The area must be representative of an important agricultural region where erosion is a problem. It must be easily accessible. The farmers should be at least moderately thrifty and have a live interest in the land.

After the area has been selected, a suitable town within or adjacent to it is chosen as headquarters for the project. A project manager and a staff of technicians and office members, usually a total of between 12 and 20 persons, are selected and assigned to the project. In addition to the project manager, the technical staff ordinarily consists of an engineer, an agronomist, a soils specialist, a forester, a farm-management expert or farm planner, and, where necessary, a range examiner, and a biologist who plans features relative to rodent control and wildlife. There are also technical aids to these men and the necessary clerical, stenographic, and warehouse personnel.

Shortly after a project is established an aerial photograph is made on a scale of 8 miles to 1 inch. This serves as the base for the planning and detailed mapping of the farms within the area.

A group of staff members begins careful studies of the type of erosion present and of the agricultural practices within the area in order to develop a satisfactory soil and water conservation program and work plan. The same or another group gives its attention to presenting the general plan to the farmers of the area to enlist their cooperation.

As soon as the farmers of the area have been given an understanding of the purpose and type of work proposed and the technicians have developed a sound preliminary plan, efforts are directed toward making more detailed plans for the farms of those landowners and operators who wish to become cooperators. Such technicians as are needed work together in preparing the plan of conservation operations for the farm.

The plan of conservation operations includes plans for the desirable and necessary structures, land-use practices, and cropping arrangements over a 5-year period. All plans are developed with the farmer and are designed to control soil and water losses on his farm and at the same time as nearly as possible meet his requirements for income from the land. When a satisfactory plan is completed it is included as part of a formal cooperative agreement between the farmer and the Government and signed by both parties. This agreement also specifies what each party agrees to furnish with reference to materials, labor, equipment, and technical assistance, and indicates which party to the agreement will carry out its various provisions. All details of the plan are fully explained and set down in the agreement. In all cases an effort is made to avoid committing the Government to furnish more than half the materials and supplies necessary to initiate the farm program. The farmer performs all regular farming operations and also contributes additional labor in many cases. Any labor furnished by the Government is from C. C. C. camps, from relief rolls, or by regular Government employment.

There are harmonious relationships between the project technicians and the farmer; they cooperate in getting the work done in keeping with the agreement. Terraces and other structures are built, trees are planted, grasses and legumes are seeded, cultural operations are followed, and all features of the entire plan are put into effect in season.

From 2 to 2½ years are required to plan and apply measures on a sufficient number of farms to provide a good demonstration in the area. In some cases it may be possible to work 20,000 acres, while in others completion of 12,000 acres may satisfy the requirements of a good demonstration. This period of full activity is designated as the operations period. Following this is the maintenance period, which covers the remainder of the 5-year agreement period with individual farmers. During the maintenance period no new plans or work are undertaken. Approximately one-half the staff remains on the area to amend agreements where necessary, finish fulfillment of obligations of the Government, and advise, aid, and encourage the cooperating farmers and others in the area to follow their program in the most accurate manner possible.

Figure 1, *A* and *B*, shows a model of a demonstration area. The eroded areas are readily noticeable in *A;* this condition existed despite the fact that the slopes are not excessively steep—averaging about 6 percent, and for the most part not exceeding 12 percent. An appreciable area of cropland was terraced before the project work was started, but many terraces were improperly constructed, and in these cases the results have been unsatisfactory.

The darkest, heavy, roughened parts on both *A* and *B* are the woodland areas. The uneven appearance of these areas marks them from the next darkest areas, which are permanent pasture lands, or, in figure 1, *A*, in some instances idle or abandoned areas. The lightest areas are the croplands, and on some fields the interspersed strips of darker areas are a part of the complete system of contour strip cropping. The terraces are evidenced by their apparent projected effect.

For comparison, attention is called to the upper right portion of the pictures. The uppermost field in figure 1, *B* is strip cropped, with alternate bands of clean-tilled crops and close-growing crops laid out on the contour or perpendicular to the prevailing slope. The cultivated field immediately below this topmost field in the picture is terraced, and the area between the two fields is devoted to permanent pasture. The area in the uppermost right corner of the picture is in woodland now, protected from grazing and fire.

Comparison of *A* and *B* will show the parts of these farms that have been retired from the cultivated area to more erosion-resisting uses—permanent hay, permanent pasture, or woodland. Also, on figure 1, *B* wide strips of meadow are obvious in the draws, where they serve as terrace-outlet waterways. A comparison of the two pictures reveals that in practically all instances the gullied areas noticeable on *A* have been cared for by the revised plans now in effect.

A demonstration is established more effectively and accurately with the active cooperation of several agencies. The various State agricultural colleges and other State agencies furnish fundamental

assistance in this type of project. The area itself is selected largely on the basis of studies and recommendations made by the State college of agriculture. The educational work in spreading the findings of the project is the function of the State extension service. The staff of the State experiment station assists in developing a work plan for the project and furnishes experimental information and advice to tech-

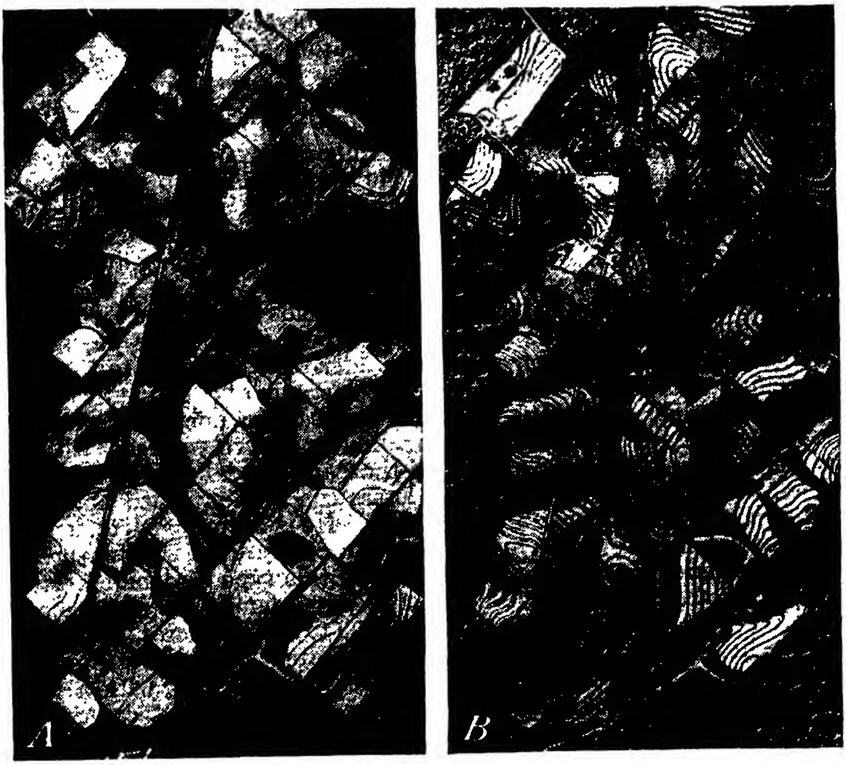

FIGURE 1.—Photographs of models patterned after actual land conditions of a small watershed area of 38 farms covering 3,200 acres along Indian Creek in the Coushatta demonstration project area of Louisiana: *A*, Before treatment; *B*, after treatment.

nicians in connection with the application of practices. The State agencies are encouraged to follow up certain lines of investigation and education that develop as a result of changes of agricultural practices in the area but are not definitely a part of the soil and water conservation program.

Other State agencies such as vocational departments, planning boards, and forestry and conservation departments have opportunities for active cooperation with the projects. Various bureaus in the Department of Agriculture as well as agencies in other departments of the Government are also cooperating on problems of mutual interest.

Effectiveness and Limitations of Soil Conservation Demonstrations

The effectiveness of a demonstration is often correlated closely with the degree of interest shown by the farmer cooperators. In some instances, the farmer interest is in proportion to the contribution farmers have made to the work. On the other hand, many who were skeptical and either would not cooperate or, if cooperating, contributed little, become active cooperators after observing the results of the demonstration.

Some individual farmers will not at first accept certain control measures. But where similar or the same control measures are applied successfully to the farms of neighbors in the community, the more skeptical farmers soon amend their agreements to include such treatments. Community interest and opinion is recognized and utilized in order to bring about the widespread acceptance of worthwhile erosion-control measures, especially those which have an influence beyond an individual farm.

Farmers are noting the increase in crop yields on planned farms; the reduced danger of crop failures during droughts; and the possibility of maintaining the farm income even under restrictions as to the area now cultivated. Probably the greatest measure of effectiveness is the farmer's change of outlook in many areas from one of despair to one of hopefulness. After Federal technicians have worked with him in the field in attacking problems that appeared hopeless to solve alone, the farmer realizes that soil losses can be controlled and feels that again he is master of the situation. He is encouraged to remain on the land and work out his problems in cooperation with nature.

In the period from October 1933, when this type of demonstration work was started, until October 1, 1937, 165 demonstration projects on private land, ranging in size from 8,000 to 200,000 acres, have been established. One or more projects are located in each State of the Union except three. These areas contain 64,446 farms with a total acreage of 8,482,089. During this period 22,875 farmers, controlling 3,421,474 acres, have entered into cooperative agreements with the Soil Conservation Service that will involve the establishment of full erosion-control measures and practices. Up to October 1, 1937, work had been started on 2,755,301 acres, of which 1,726,914, or 63 percent of the total area, have been completed. This work includes such major practices as strip cropping, contour furrowing of pastures, pasture improvement, terracing, tree planting, construction of small dams for water conservation, and water-spreading and gully-control work. Approximately 9 percent, or 240,081 acres, of the land under treatment have been retired from cultivation to permanent grass or woodland.

It is recognized that soil and water losses are usually greatest on cultivated lands. In examining changes in land use under an erosion-control program, it is significant to note that while there were 1,719,056 acres of cultivated crops before work started in these areas, there are now 1,478,975 acres in cultivation; and the acreage of erosion-resisting crops in the same areas has increased from 290,864 acres to 373,505 acres.

One serious limitation to the extensive use of this method of remedial action is the large financial outlay necessary for the Federal Government to establish and complete a full demonstration in one locality while other parts of the State are receiving no assistance. Although there has been a marked reduction in the cost of this work, it continues to be an expensive procedure. Federal contributions must necessarily be considerable in cases where a new practice or plan is being presented to the farmers. The merits of this approach are manifest in the educational value that leads to the extensive adoption of well-coordinated practices by farmers outside the area itself and the public benefit from conservation of an irreplaceable and basic national resource, the soil.

There is no positive assurance at present, however, that, without land-use regulations, some of the newly established practices might not be discarded by farmers should they decide that it would be to their immediate economic advantage to do so. This is especially true where agriculture is on an exploitative basis, under certain cash crops with fluctuating value, or where tenancy, particularly on short terms, prevails.

In order to be assured that practices established and in operation for 5 years are continued as planned, well-informed guidance and assistance should be available to the farmer. Certain unusual climatic catastrophes, such as severe rains or droughts, may so disturb structures and plans as to require the assistance of trained personnel in helping the farmers make correct adjustments. This incurs an obligation for continued and adequate technical services to farmers of the Nation.

Many of the consequences of erosion extend beyond the boundaries of the farm, the community, and even the State. There is reason to believe that, with the careful application of this area-demonstration program in which interested agricultural agencies may join in working with the farmers, a definite advancement can be made toward a more stable and safe agriculture.

SOIL SURVEY AND RESEARCH

The general objective of soil research is to determine the kind, yield, and quality of plants that can be produced under alternative systems of management, physically defined, on the various types of soil, and the influence of these systems of management on the long-time productivity of the soil. Such knowledge should be broad enough to include all the major types of soil in the Nation and to be applicable under a range of economic conditions. The data must permit the evaluation of the relative advantage of various soil types under particular practices and the relative advantage of different practices on the same soil type.

Such a program should not be undertaken lightly. Our agriculture is complex and will become increasingly more so. Adjustments in land use to achieve the ends of production and conservation cannot be made according to any set pattern. Since our country has large areas of many types of productive soils, and consequently a wide diversity of types of farming, the physical conditions are especially favorable in the United States for the development of agriculture to a very high level from the point of view of both individual and national security.

The progress of soil science in the United States has been slow as compared with that of many of the other sciences, partly because of the late recognition of soil problems by people generally. Future progress is limited by a lack of fundamental data, especially for portions of the country having soils unlike those investigated by the older research institutions in Europe.

Although research work in soils must proceed along several lines, it is impossible to overemphasize the necessity for having its many phases closely coordinated. One of the principal reasons for the meager progress up to date—meager, that is, compared to the present need—has been the piecemeal fashion in which much of the work has been conducted. As a matter of fact, a considerable portion of our present knowledge has been gathered "on the run," incidentally to other activities. Since progress in any one phase of the subject is associated necessarily with progress in the other phases, a serious lag in any one may handicap or even prevent progress in the others. Various lines of soil study—morphology, classification, genesis, geography, chemistry, physics, fertility, microbiology, and mechanics—should advance together and with the other phases of agricultural science. From a practical point of view, for example, it is of little use to make chemical analyses of soils, study their fertilizer requirements, or determine their erodibility, unless there are accurate maps showing where the individual soil types occur in order that the results may be applied by farmers. On the other hand, a soil map is useful only insofar as the characteristics of the soil types shown on the map and their responsiveness to various types of management are known or can be determined.

The research work must be purposeful. It must be oriented by the agricultural problems to be solved yet proceed along lines that are fundamentally sound from a scientific point of view and clearly separated, administratively, from any extension or "action" programs. Worth-while research can best be accomplished in an atmosphere of stability and academic freedom. The soil scientist must determine soil boundaries in the field and read his instruments in the laboratory strictly in accordance with the scientific facts, and these alone, regardless of the possible inferences to be drawn from these facts in respect to any existing economic, political, or scientific theories.

Investigations Needed

The study of soils to obtain information necessary for determining their best use proceeds along four general lines. These are by no means mutually exclusive. They should go along more or less concurrently, since advancements in one field lead to suggestions for improvements in the others, although they can be arranged in a logical order.

(1) The identification and mapping of soils in the field.

(2) The determination of the morphological, physical, chemical, and biological characteristics of the soil types.

(3) The determination of the responsiveness of soil types to management, including tillage, fertilization, crop rotations, and water control (drainage, terracing, and other erosion control devices, and irrigation).

(4) Determination of the use capabilities of the soil types on the basis of the physical data and of experience.

Soil-Survey Needs

There are about 2,850,000 square miles in the continental United States having reasonable possibilities for the production of crops, grasses, or trees. Satisfactory detailed soil maps on a scale of 1 inch to the mile for about 840,000 square miles and reconnaissance or schematic maps on smaller scales for a considerably larger area have been prepared since soil-survey work was initiated 40 years ago. Some of the existing maps are not sufficiently precise for the detailed planning of farm operations. Furthermore the techniques for soil-type[2] identification and mapping have been greatly improved during the course of the work, and attacks on our present-day agricultural problems require maps of much greater detail than those formerly suitable. According to the best estimates available detailed soil maps need to be made for about 1,250,000 square miles and less detailed or reconnaissance soil surveys for about 880,000.[3] Costs for the field work and publication of detailed soil maps are about $25 to $40 per square mile and for the reconnaissance soil maps somewhat less. The completion of the soil survey of the continental United States would cost from $35,000,000 to $50,000,000, depending upon the base maps available from other projects and similar factors. This cost seems rather large by itself, but it is very small indeed when compared with that being spent by public and private agencies to promote stability of agricultural production and income, conservation, flood control, and the improvement of farm homes through better use of our soils.

Soil surveys are completed, or nearly so, for Puerto Rico and Hawaii, but very little is known about the soils of Alaska. A large portion of Alaska is relatively unimportant for the commercial production of plants, but probably between 70,000 and 80,000 square miles have possibilities. Of this a portion should be mapped in detail and the remainder in reconnaissance.

Soil maps are essential to the soil-research program, of which their production is an important part, and to the practical application of the findings of such research to the land and the people. Although the survey provides an inventory of soil resources, this is one of its least important features. Primarily it serves as a basis for classifying the results of experience and experimentation regarding the characteristics and use capabilities of soils in order that these results may be applied to each individual unit of operation.

Characterization of Soil Types

The soil types recognized in the field and shown on soil maps are each characterized by particular internal and external features. The internal characteristics are the result of the combined influences in the natural landscape which produced the soil. In order to understand the basic properties of a soil that are important to the growth of plants, its physical, chemical, and biological constitution must be determined. These studies may be grouped conveniently under four principal heads: (1) Morphological studies in the field, (2) physical

[2] The term "soil type" as used throughout this article refers to a group of soils having essentially the same internal morphology and external features of climate, slope, stoniness, etc. Thus it includes the concept of "phase" as used in soil classification.

[3] This figure includes many small areas of waste land.

studies in the laboratory, (3) chemical studies in the laboratory, and (4) microbiological studies in the laboratory.

Morphological studies in the field include the determination of the depth, structure, and other visible characteristics of the several layers which make up the soil in which the plant roots develop and from which the plant obtains its nourishment. Only with the background of these data can soil samples be collected for the laboratory or the results of laboratory work be interpreted accurately. A large part of the costly work done in the laboratory in the past has been of limited use because of poor sampling. Many of the samples were not representative of anything and others of only a surface layer.

The lack of precise data regarding soil morphology is particularly serious at present, especially for soils which have been cultivated and through use have had their natural characteristics altered by tillage, fertilization, cropping, erosion, and similar influences. Particular attention should be given to the rate of soil formation under different environmental conditions and to the stability of the various soils under different management practices. Some soils lose their desirable structure or erode under management practices which improve the productivity of other soils. Although our country affords unusual opportunities for studying these changes in morphology, little has been done. The results are needed urgently now, for such data are essential for developing recommendations for the use of soils on a permanent basis.

More precise physical measurements than are possible in the field are also necessary. For example, studies of structure in the field need to be supplemented by laboratory determinations, both on the structure itself and on its stability. The water-holding capacity of the soil and its ability to give up this water to plants should be determined. These moisture relationships are controlled by the structure of the soil, the chemical nature and amount of soil colloids, the content of organic matter, and especially the depth and arrangement of the several soil horizons. The properties of the soil may vary greatly between different layers and may be altered somewhat through use, as by tillage, erosion, irrigation, and drainage. From the point of view of methods of analysis considerable progress has been made in this field, but more precise methods for measuring the amount of available water in the soil as it exists in the field and the rate at which it can be supplied to plants are needed.

Chemical investigations have been in progress for a very long time. Here again, although progress has been rapid during the past 10 years, methods, especially for the determination of the amounts of the various nutrients available to plants, are urgently needed.

Although a good deal is known about certain soil types, present knowledge regarding the chemical nature of the soils of the United States is wholly inadequate and many lines of work must be developed in order to furnish the necessary data. These chemical analyses must be supplemented by controlled experiments with growing plants in order to establish the relationships between the nature of the soil and the ability of the plant to obtain from it the materials needed for normal functioning and growth, in respect to both yield and composition. The most pressing needs may be listed briefly as follows:

(1) Chemical analyses showing total composition and available nutrients are lacking for a great many of our important soil types. Studies on the content of minor elements in the soil and their influence on plant nutrition should be included.

(2) Precise data regarding the products of hydrolysis of specific minerals and compounds found in the soil must be developed for the interpretation of the results of physical and chemical analyses.

(3) Reliable methods for determining the fertilizer needs of arable soils through "quick tests" are needed urgently in order to place fertilizer recommendations on a satisfactory basis.

(4) Mineralogical analyses of soils and other research are needed in order to discover the compounds responsible for "fixation" of fertilizers in the soil, the degree to which different fertilizers are "fixed," and ways whereby undesirable fixation, which makes nutrients unavailable for use by plants, may be overcome. This problem is particularly important with many of the soils needing phosphate fertilizers. Frequently, when phosphates are added to the soil, they are fixed so quickly and so firmly as to be useless to plants.

(5) More precise information is needed regarding the physical and chemical changes in arable soils as a result of use. Important, but largely unknown, changes are brought about by the crop plants themselves and through tillage, fertilization, erosion, and in similar ways.[5]

(6) Research is urgently needed to establish the relationship between the nature of the soil and the quality of food plants which may be grown on it as a basis for improving quality through selection of crops for specific soil types and through proper fertilization.

One of the most promising fields for future research in soils is that of soil microbiology. Most of the work heretofore has been done in the laboratory in order to determine the characteristics of particular soil organisms. Findings of significance have been made, especially in regard to organisms associated with legumes and otherwise of importance in nitrogen nutrition. Up to the present, however, extraordinarily little has been done to determine the differences in micropopulation between actual soil types. The technical difficulties involved in such research are great, but equally great is the importance of the results.

Determination of Response of Soils to Management

In order that farmers may plan their operations to the best advantage, knowledge must be available regarding the use capabilities of the soils on each farm. The largest part of this information is gained from the farmer's own experience and that of other farmers on the same types of soil. As a matter of fact much of our present knowledge regarding soils has been gained from an analysis of farmer experience, although science has developed new methods and improved many of the old ones.

Another important part of our knowledge, especially regarding new methods, must be obtained from experiments designed to determine the suitability of various methods of management for the different soil types. Experience of the last few years testifies to this need. Although important leads and suggestions may be obtained from a consideration of the physical and chemical nature of the soil and the requirements of plants, it is necessary to conduct experiments, under controlled conditions, on the soil types in order to determine accurately the most practical method of management. Constantly it must be borne in mind that soil productivity is a matter of both husbandry and soil. Certain soils may be inherently unproductive for particular plants under natural conditions but at the same time may

be very responsive to management and offer possibilities for the development of a fine farm when properly managed.

The principal problems to be attacked by these investigations may be listed roughly as follows: (1) Crop rotations adapted to each of the soil types, including time of seeding, length of rotation, strip cropping, and similar variations. (2) Methods of tillage adapted to the various soil types with different rotations, including methods of plowing, contour furrowing, listing, and other devices designed to achieve the ends of production, maintain the structure of the soil, and prevent its loss through erosion or blowing. (3) Needs of the soil types for lime and fertilizers, including amounts and kinds of these materials for various rotations adapted to the soil, methods of placement, and time of application. These researches must include the necessary laboratory work for determining how the fertilizers should be manufactured in order to produce the best results. (4) Methods for water control, including irrigation, the drainage of poorly drained soils, and the prevention of excessive run-off through the use of terraces and other devices.

In addition there are special problems, including the reclamation and use of bog soils and saline soils and in the production of special crops.

It should be obvious at once that conclusions regarding any one of these problems cannot be reached without a consideration of the others.

It would not be desirable or economically practical to attempt a trial of all possible systems of management on each soil type. On the basis of initial field investigations and the laboratory investigations the most likely systems for trial may be determined. Unquestionably, a large portion of the effort devoted to field experiments and plot work in the United States in the past has not given maximum results owing to a lack of careful planning. Many of the field trials would have been eliminated if initial investigations had been made in the greenhouse—and information preliminary to greenhouse tests is often obtained in the laboratory. A great many field experiments will always be needed, but they are costly, and every advantage should be taken of the facilities of the laboratory and the greenhouse to eliminate those that are unnecessary.

When the necessary data regarding the effectiveness of different management practices and combinations of practices on various types of soil are available, the recommendations for an actual farm depend upon the prevailing economic and physical characteristics of the farm unit. Relatively few farms have uniform soils; they consist rather of combinations of several soil types. Whether a farmer should grow corn on a particular soil type, for example, will depend upon the kind of soil available in other fields of his farm. A certain type of soil may be best adapted, from a physical point of view, to the growth of legumes and grasses for pasture, but with the use of strip cropping or terracing corn can be grown on it. If one farmer has other land well suited to corn he may find it more practical to use this particular soil type for pasture. A neighboring farmer may have no other soil as suitable for corn and may find it more practical to use this particular soil type for corn, and use other soil types for pasture. Many instances of such necessary variations in use of soil types can be observed on good farms in any complex soil region.

The soil-research program should be designed to furnish information regarding the capabilities of the soil types under different systems of management, but the actual management system for any particular farm should be determined by a consideration of additional factors, such as expected prices and costs of production. At the same time the soil scientist must be aware of limits of practicability and not carry his investigations in the applied field to the point of investigating management practices obviously beyond the reach of any operator.

Capabilities of Soil Types for Use

It is not sufficient for the soil scientist to identify soil types in the field, show their distribution on maps, determine their characteristics, and measure their responsiveness to management practices. These data are necessary, but in addition they must be interpreted and assembled in such a way that they may be available for use by those who plan the operation of farms—the farmers themselves. Recommendations should be made to farmers with full cognizance of the fact that available choices depend upon the capabilities of the soil under existing economic conditions. What may be a desirable practice today may not be a desirable practice a few years hence. What is a desirable practice on a soil type on one farm may be an undesirable practice on the same soil type on another farm differently situated from an economic point of view. The soil scientist must always guard against condemnation of particular soil types. New techniques are constantly being developed. Soil types thought to be useless for agriculture a generation ago are producing well today.

Interest in soil science is developing rapidly in the United States. Although important advances have been made in particular phases of the science, other phases have been neglected and further progress will depend upon the strengthening of research in the fundamental aspects of the science and coordination of the whole. Since soils are out of doors and are used out of doors, the investigations cannot be confined to a laboratory. Useful research can be accomplished only through combined field and laboratory studies. This fact makes the problem of coordination difficult but in no way minimizes its importance.

Whereas many other nations have few soil types, the United States has a very great many, differing enormously in kind and in quality. The problems in both the fundamental and applied phases are correspondingly complex and require a great deal of specific information for their solution. The temptation to oversimplify soil problems pressing for solution and to generalize from too few particulars will be great. To the extent that soil scientists succumb to this temptation, their usefulness to American agriculture will be limited.

LAND-USE PLANNING AND LAND CLASSIFICATION

Public planning of the use of land has two important phases—(1) determination of the uses that do and those that do not promote the general welfare and (2) formulation of measures of public policy that will secure the adoption of the desirable uses. Land-use planning by public agencies may therefore be said to consist in making two sets of decisions—(1) as to what uses of particular bodies of land are to be sought, and (2) as to what means shall be used to attain or encourage

these uses. The first process has been called land classification, though land-use classification would be more accurate.

Two types of land-use classification may be recognized. The first shows the cropping or grazing system or soil-management practices suited to a body of land. The second shows the kind of organization for use to which an area is deemed suited; that is, what type and size of farm, for the farming areas, and what size and organization of operating units for the areas not suited to farming. Both of these types of classification have been carried on in varying detail during recent years in different parts of the country. Neither needs to be carried out everywhere to the same degree of detail.

Different Areas Require Different Techniques

There are some areas in which the chief reason for applying measures to influence land use is to prevent waste of the soil. In many of these areas, farmers can afford to practice the measures needed to mitigate soil waste, such as proper soil management, crop rotations, terracing, strip cropping, or contour furrowing, and no change in the size or type of farm appears necessary to enable them to do so. Here land-use planning would be directed largely toward the determination of cropping practices and erosion-control measures suited to the different soil types, and toward devising means for inducing farmers to follow such practices, such as education, direct economic inducements, or regulations. Land-use classification in this case would be of the first type.

In other areas the problems of land use are mainly those of soil depletion, but the farmers cannot afford to take the measures necessary to mitigate soil losses, for to do so would reduce their incomes to too low a point. Here the public must make it possible for farmers to conserve the soil yet earn a livelihood. More extensive uses, which mean larger farms, may have to be sought if the soil is to be used conservatively, and until the change can be made, compensation to farmers for a shift to less intensive crops may be justified. In this situation land-use planning is concerned with seeking soil-maintaining uses plus new types of operating units capable of accommodating such uses. The question of the kind of organization for use—that is, whether farms or not, and if farms, what size and type—is an issue in areas where the existing type of organization is out of adjustment, as in the Great Plains, the cut-over regions, and some of the hilly portions of the East and South. Differentiation between areas suited to farming and those not suited and between those suited to different kinds of farm organization needs to be undertaken in such areas and also in those subject to new settlement. In regions like the Pacific Northwest and the Mississippi Delta, which are receiving many new settlers, land classification of this sort is urgently needed as a guide to settlement.

In another type of area the competitive uses of pasture and forest are in question. Ranchmen wish to burn the woods to improve the grazing, yet State forestry officials, holding that forest values are paramount, administer laws to prevent the ranchmen from burning. It is the function of land-use planning to determine which of the two competing uses best serves the general interest, and having decided

this, what measures should be applied to encourage the one and discourage the other. In this instance land-use planning might involve a recommendation that the burning regulations be relaxed to the extent of permitting controlled burning of certain forest land to permit its conversion to grazing.

The general areas in which these situations occur can usually be located without great difficulty or expenditure of time. It will be in the interest of efficiency in the use of funds to identify these situations, or "type" areas, in advance of undertaking detailed land-use classification or intensive land-use planning investigations, since the type of investigation needed will differ greatly in different areas. This work is already well advanced in many parts of the country and should be continued until the entire country has been systematically covered.

Insofar as existing land uses serve the interest of the private users without hurting the interests of others or of the general public, there is no reason for land-use planning by the public. So long as the view is accepted that private owners and users of land are responsible for determining its use, planning by the public must be directed largely toward the prevention or diagnosis and cure of maladjustment.

The systematic classification of all the land in the United States according to its best use is sometimes advocated. The term "best use" may include all degrees of particularization from such generalities as "farming" down to the details of a type of farm organization, or even to the minutiae of cropping and soil-management practices. In many situations the difficulties and expense of ascertaining precisely what use is best, down to minute particulars, would more than offset the advantage to be gained. Land-use classification should probably be carried to the point of identifying the lands suited and unsuited to farming throughout the country. Further particularization will depend upon how great the consequences are likely to be, in a given area, of not knowing the details of best use. It is the land-use classification, when accepted as the goal toward which shifts in land use should be directed, that constitutes the plan for land use in a local area. It should be repeated, however, that land-use planning consists not only in formulating such plans for land use, but in devising means for carrying them out.

Status of Land-Use Planning and Need for Further Activity

National policies affecting land use have been expressed through a considerable number of independently applied measures or programs, each designed to affect some phase of land use. The agencies charged with carrying out these measures have operated to a large extent, though not entirely, irrespectively of one another. Each has undertaken such land-use planning as it believed to be necessary in the carrying out of its program. In consequence, unified national policies and plans are lacking for an attack on many of the land-use problems of the country. This is not to say that there have been no land policies that have been accepted as good by general agreement, but rather that there has been no single, coordinated body of land-use policies, and therefore no national plan for the application of such a group of policies.

To bring about a better-integrated application of its programs and policies, the Department of Agriculture has recently appointed a Coordinator of Land Use Planning. An increasing attempt to coordinate interdepartmental and Federal-State activities in land-use programs and land-use planning is noteworthy and wholly desirable.

It has lately become more and more apparent that the coordination of policies affecting land use requires more than simply coordination of programs at national headquarters. There is also needed some kind of coordinated plan in the place where the various programs are being applied, to provide a practical goal toward which all the programs are to be directed and against which their progress can be measured. Without such a plan to use as a common goal or objective, there is danger of different measures working at cross purposes in spite of cooperation at national headquarters. The effectiveness of the different national land-use policies is dependent upon a union of effort in working out, for each problem area in which land-use adjustment programs are justified, a mutually acceptable plan or pattern of land use. It is toward the establishment of such plans that land-use classification should be directed. It should be repeated that such a plan does not need to be carried through to the same degree of particularization everywhere.

Some of the instruments for achieving land-use adjustments are in the hands of the States. Particularly is this true of enabling legislation for such measures as rural zoning, formation of grazing associations, or soil conservation districts. State agencies should therefore participate in working out area plans. Finally, counties or other local districts will be responsible for certain measures needed to bring about good land use, such as the enactment of rural zoning ordinances, the establishment of grazing associations or soil-conservation districts, or the assumption of title to chronically tax-delinquent land. Hence county or other local groups must participate in the area-planning activity. Local participation is especially desirable because the effect of local application of policy measures often cannot be fully envisioned by planning agencies far removed from the scene of actual application.

It is essential, of course, that the national interest be represented in the process of county or area land-use planning, so that the planning done will not be merely the promotion of sectional or local interests at national public expense.

In developing area plans of this kind, the responsibilities for work should probably be divided about as follows: Technical agencies of the Federal and State Governments should (1) assume responsibility for getting the necessary technical data and evidence which local groups generally have neither means nor training to secure, (2) assist local planning groups in interpreting the data and drawing conclusions from them, and (3) see that the national and State interests, respectively, are not subordinated to local interests when the plans are drawn. The county agricultural planning committees, organized in a majority of counties, have recently begun to delineate the local land-use areas within their counties and to recommend types of use for them. These committees should be encouraged to continue in this activity, and their field of interest should be broadened to encompass other aspects of land-use planning, such as devising means for bringing

about the necessary changes. Technical agencies of the States and the Federal Government should undertake to supply the committees with evidence, and should assist them in the interpretation of such evidence.

There are certain technical data that governmental agencies should undertake systematically to obtain for use in the process of area land-use planning. Common to nearly all types of land-use adjustment is the need for an understanding of the character of the land itself. The relatively stable, or nearly permanent, physical characteristics of land have a bearing on decisions regarding most uses, whenever the decisions are made. The mapping and description of land in terms of these relatively permanent characteristics does not readily become obsolete in its usefulness. On this ground, the general extension of the soil survey of the Department of Agriculture, which provides a description and classification of individual bodies of land in terms of inherent characteristics most likely to affect the growth of plants, is justified. Even this survey is more efficient when preceded by the application of a reconnaissance procedure to identify areas where detailed mapping is unnecessary on account of obvious limitations on land use imposed by physical conditions, such as aridity.

In areas where erosion will have serious consequences, it will be desirable to identify the soils that can be safely used for different purposes, such as continuous row crops, rotation with strip cropping, pasture only, forest only, etc. The conservation surveys now in progress should be continued to serve this purpose.

As rapidly as possible, a systematic procedure should be set up for recording crop-yield experience by soil types under existing and also under soil-maintaining practices. This should be undertaken first in problem areas where adjustments in the cropping system or in the farm organization appear desirable, as a means of providing evidence of yield expectancy from different soils under various systems of management. Estimates of yield expectancy help to predict income expectancy from farms of a given type of organization occupying given combinations of soil types.

In each problem area in which a shift in the type of operating units may be desirable, some analysis of the returns from using land under various types of farm or ranch organization will usually be desirable, so as to make use of the body of accumulated experience in drawing conclusions. The type of procedure used in farm management or farm business analysis should be utilized in this connection.

In these problem areas, some analysis of the public cost of different patterns of use should also be made since this must be fully considered in laying plans for land use.

A major shortcoming is the lack of any logical sequence or systematic plan for gathering technical data that might be used in the formulation of area land-use plans. There are soil surveys in one area, farm-management studies in another, and studies of the public finance aspects of land use in another. Seldom have the different types of evidence needed all been obtained for a given area. Attempts at coordination of its survey activities have recently been made by the Department of Agriculture to remedy this difficulty. In Montana the State Agricultural College has succeeded in working out a coor-

dinated procedure for assembling the data needed in the process of making area land-use plans.

Land-use planning must also be concerned with ways and means for bringing about the pattern of use mutually agreed upon. This may mean selecting appropriate measures from among those now in operation, or it may mean devising new means for implementing land-use adjustments. To do this may require a study and analysis of the operation of different types of programs and policy measures. In considering ways to implement land-use adjustment it will be necessary to consider certain institutions that serve to block the attainment of efficient land use. Where traditional forms and features of farm tenancy, for example, make it practically impossible for socially desirable soil uses to be practiced by tenants, land-use planning must be concerned with finding and recommending ways to remove such impediments to the achievement of good land uses. Research into the operation of the many social and governmental factors that control or influence land use is requisite if changes in laws, in local governmental organization, and in other social arrangements are to be recommended.

Appraisal of the legal and public fiscal arrangements affecting land use, with the aim of making intelligent recommendations concerning their modification, is a definite part of the land-use planning program of the Department of Agriculture and of State agencies in some States and should be continued as an important complement to the other phases of land-use planning.

AMONG the land owners in this country are the Federal Government and the States. Extensive acreages are included in the public domain of the West, in the national forests with their range land, and in State-owned land. These areas are subject to erosion and to misuse just as private lands are. What are the outlines of wise policy for the conservation and best use of their soil? How and under what circumstances should public purchases of land be made in the future? These questions are considered here.

The Remedies: Policies for Public Lands

By Earle H. Clapp, E. N. Munns, I. H. Sims, George S. Wehrwein, *and* C. F. Clayton [1]

THE PUBLIC DOMAIN

THE PUBLIC DOMAIN [2] of the western United States is a paradox. It consists of land with values so low that, despite the many generous land laws of the Federal Government, it could not be sold or given away or otherwise disposed of over a period of 75 years. But despite this the public domain is of great social and economic importance to the West and hence to the entire United States. This is because its 162 million acres contain nearly 130 million acres usable for range-forage production. On this area the equivalent of no less than 1½ million horses and cattle and 6½ million sheep and goats have been grazed during recent years for an average grazing season of 7 months a year.

The public domain also makes up a substantial part of the watersheds of many of the major western streams and those of innumerable smaller ones. From these watersheds may come benefits in water supplies where scanty rainfall makes water the limiting factor in all development, or from them may come destruction and disaster in floods and silt-burdened streams.

Before suggesting ways to insure proper use of the soils of the public domain, it is logical first to inquire what the condition of these soils is now.

[1] The section headed The Public Domain is by Earle H. Clapp, Associate Chief, Forest Service. The section headed The National Forests is by E. N. Munns, Chief, Division of Forest Influences, Forest Service, and I. H. Sims, Silviculturist, Northeastern Forest Experiment Station, Forest Service. The section headed Management of State-Owned Lands is by George S. Wehrwein, Professor, Department of Agricultural Economics, College of Agriculture, University of Wisconsin, and the section headed Public Purchase of Land is by C. F. Clayton, in charge, Division of Project Organization, Bureau of Agricultural Economics.

[2] The public domain as here used includes land that was unappropriated, unreserved Federal land, exclusive of Alaska, prior to the approval of the Taylor Grazing Act.

Only about 2 percent of the usable range area, according to the best information available, is free from erosion. Of the 98 percent that is eroded—that is, over 19 acres of every 20—nearly half is severely eroded. More than one-third is contributing soil to streams at an alarming rate.

On the range, as everywhere, erosion first removes the fertile topsoil. For the range soils this means that the moisture-holding capacity and the fertiilty for plant production has been greatly reduced. While the great volume of erosion takes place as a relatively slow, insidious, little-recognized process, its most spectacular form occurs in floods and mud flows. And unfortunately, practically all the evidence at hand indicates that the rate of erosion has been increasing and that floods are becoming more and more destructive.

The why of this practically universal and accelerating erosion may in itself suggest the means for control.

From the earliest settlement until recently, public-domain ranges have been a no man's land open for the use and abuse of any and all who could take and hold them. All the incentives were for overuse and none was for range conservation. Long-continued overuse and mismanagement could have only one result—range depletion. And the best information available indicates that the range cover has been depleted nearly 70 percent as compared with its original or normal condition. Drought and other factors have of course contributed, but the primary cause of the depletion is overuse together with the lack of better forms of management.

Sparse though it may usually have been, the normal range cover afforded great protection to the soil from erosion, and the depletion of the cover has been the primary cause of the serious increase in erosion of the last few decades.

The obvious and, in fact, the only way to rebuild and protect the soil of the public domain is to restore the range cover. Any other means of restoration and form of control would involve expenditures so great that they would make the undertaking questionable and even though carried out would undoubtedly prove ineffective in the long run without reestablishment of a range cover.

One means to restore the range would be to give it a complete rest. But to give complete rest during rehabilitation would uproot over a period of years the long-established livestock industry. This is unthinkable because of the social and economic distress it would cause.

The alternative is the managed use of the range, which should include such things as:

1. Confining the numbers of livestock to those safely within the limits that the range can carry through the years. Even this will require some drastic readjustments.
2. The regulation of seasons of use by livestock so that the worth-while range plants can reoccupy the land.
3. Use by the class of livestock for which on specific areas the range forage is best suited.
4. Reseeding where the original cover is so far gone that it cannot replace itself naturally.
5. Fencing, water development, and other improvements and forms of management incidental to regulated or controlled use.

The opportunity for such management is afforded by the Taylor Grazing Act, probably, as experience will show, in amended form. A large-scale test on public lands extending over many years has proved that the task of putting the public domain under administration is not insurmountable.

The magnitude and the difficulties of placing the enormous area of public domain under management should not be minimized. Depletion of the range and deterioration of the basic soil have gone so far that restoration will probably require at least as many years as did depletion and deterioration to the present condition.

Climatic conditions, rarely good, may for years on end be adverse. The often exceedingly complex land-ownership pattern can probably be remedied only very slowly. Serious existing economic maladjustments cannot be corrected overnight, and in fact may require years. Changes in the form of range use must necessarily take into account and ramify all through other interrelated forms of agriculture. Long-range planning that takes all agriculture into account must try to prevent a repetition of a long series of past mistakes in both public policy and private action. Some social hardships will undoubtedly result from the social readjustments that will necessarily follow the substitution of ordered management for indiscriminate use. A more or less radical psychological change among range users will be necessary. Although ample for great improvement, the scientific basis for sound range management and soil use exists as yet only in part.

But all of these things are merely indications of the price that must be paid for the disregard of nature's laws over half a century or more. Unless the price is paid a substantial part of the public domain area will become a desert, in fact if not in name, and will be incapable of any service whatever to human life and welfare.

THE NATIONAL FORESTS

In the administration of the forest reserves [called national forests since March 4, 1907] it must be clearly borne in mind that all land is to be devoted to its most productive use for the permanent good of the whole people, and not for the temporary benefit of individuals or companies. . . . where conflicting interests must be reconciled, the question will always be decided from the standpoint of the greatest good for the greatest number in the long run.

This policy, adopted on February 1, 1905, by the Secretary of Agriculture, guides the use and development of 175,000,000 acres of forest and range land in the national forests. It remains today the soundest policy of soil use yet formulated, broad in concept, simple and direct in language, flexible, creative, and permanent in concept.

But these very qualities raise problems of relationship, of methods and technique, of priorities, of time and trends, of human values, of social and economic interaction. To the extent that these problems are correctly solved and the solutions applied in administration of the resources, the objectives of the policy will be met.

To carry out the policy adequately requires (1) factual knowledge and (2) wisdom in the application of that knowledge. Two broad classes of problems are presented, one involving the what, how, and why of biological, pedological, social, and economic phenomena, and the other involving the application of the solutions obtained for the first.

Technique of Soil Use and Vegetation Management

The national forests were established primarily to furnish supplies of wood for the Nation and to control stream flow. When the first national forests were set aside in the West, range land interspersed with forest was included to round out administrative units. Recently, eastern submarginal farm land in need of reforestation has been acquired. Areas suited to permanent agriculture have been avoided. Soil use, therefore, is limited to natural vegetation—trees, brush, and wild forage plants. Climatic factors largely dictate the choice between these three for any given locality.

The extent of the national forests and the low-unit value of the timber and forage produced preclude intensive cultivation and care. Management methods, to be useful, must simulate natural processes, maintain natural conditions, be comparatively inexpensive, and be applicable over large areas; to be safe, they must be based on fundamental relations and reactions of soil, plants, animals, and climate.

Forest Lands

All of the major soil groups representative of the humid regions of the country are found on the national forests. Moreover, practically all of the 500 species of trees native to the United States are present in different associations or types of forest. The number of situations available for study is further increased by gradations in condition of the forest cover due to past treatment. Altogether, there are probably hundreds of combinations of soil, forest type, and condition that merit study.

European investigators have done much to clarify concepts of forest soils and to provide a satisfactory basis for classifying them. Good and bad conditions have been pointed out and some advance has been made in explaining the course of development or deterioration associated with different forest types. There is need, however, to extend much of this work to cover climatic and forest conditions of importance in this country but not represented in Europe. The studies should be extended also to yield more satisfactory answers as to cause and effect in the relationships recognized.

In this direction, more intensive study of the flora and fauna of the litter and soil should be fruitful. Exploratory work indicates that fungi, bacteria, protozoa, and minute animals are present in tremendous numbers, that they conserve vital elements of fertility, contribute to soil porosity, are indispensable in maintaining the supply of colloidal organic matter in the soil, and that different species probably have specialized environmental requirements.

At present, studies in the fauna of forest soils are still in the stage where taxonomy and classification of the organisms are incomplete. Functional relationships of the species and genera are largely a matter of surmise, and the technique of extracting the smaller, near-microscopic forms from the soil is still a matter of dispute among the half dozen or so workers in the field. Requirements and tolerances of the species and their reactions to major environmental changes are matters of conjecture.

A clear understanding of the role of the soil and litter organisms might go far toward indicating the way in which silviculture can con-

tribute to soil improvement through control of density and composition of the stand. The evidence is fairly clear now that certain species of trees are soil improvers and that mixed stands are also beneficial. The causal relations involved are less well understood.

The degree of success attained in reforestation will depend in large part on the accuracy with which the fertility level of the soil is judged. Tree species, like other plants, are known to have different fertility requirements, both for survival and for maximum growth rate. There is urgent need to determine the minimum and optimum fertility and moisture levels for the more important tree species, and it is equally important to devise simple, reliable indices for both fertility and moisture conditions of soils now barren or with herbaceous or shrub cover.

Many difficulties have arisen in reforestation programs because soil has not been adequately considered. Thus there have been costly efforts to remedy mistakes; in a few cases established nurseries have had to be abandoned because the soil was not suited to the species.

The part that soils play in the success or failure of planting programs has not been adequately recognized. The fact that climatic conditions make a region suitable for the growth of a valuable species or that a given type of forest once grew in a given locality is not a sound reason for believing that such species or types would generally succeed. Efforts to plant walnuts and other valuable hardwoods on eroded submarginal lands signally failed until it was realized that the soil had changed materially since the land was first cleared. The problem of eroded land is closely linked with that of heavily burned lands. Thus efforts are being made to plant trees on the sand plains of Michigan, which were once covered with magnificent white pine but now, after repeated fires, carry only scattered scrub oak. The aim is to restore the original forest of white pine in a single generation, but research is needed to determine whether the fires have resulted in such soil depletion that soil building under inferior species is necessary before the more valuable species can succeed.

European foresters have gone to considerable lengths to fertilize poor soils and thereby to increase forest yields. It is believed that under American conditions such practices are not needed, but so little information is available as to the requirements of American forest trees that it is impossible to foretell what may be done. In the prairie and plains region especially the problem of growing trees is so closely related to soil conditions and species requirements that until considerable research has been conducted the degree of ultimate success will be constantly in doubt.

Problems equally great face the forester in his silvicultural operations. In efforts now being made to maintain forest types in a static condition on a basis of reproduction alone, soil type or changes in the soil due to cuttings are not being considered. Notable failures have occurred for no apparent reason but with indications that soil might have been the important factor. Soil deterioration takes place even under forest, and investigations are needed to determine what species will aid in building up the soil and in preventing the formation of raw humus or podsol.

Range Land

In general, knowledge of the soils of the range lands is deficient along the same lines as knowledge of forest soils. In the broad sense, on range as well as in forest, sound soil use must be based on results of studies not only of the soil itself and its relations to the plant cover, but of the growth habits, physiology, requirements, and responses to treatment of the plants. Without this fundamental background, range management, as well as silviculture, is likely to involve a larger measure of art than of science.

In one respect, correct use of range forage plants, and hence of soil, is more difficult to achieve than the correct use of timber species. Forage crops are harvested by domestic or game animals and a technique for control of this use is necessary. Here again fundamental studies seemingly independent of the soil are required—studies of the life history, behavior, nutrition, food preferences, habitat requirements, etc., of animals.

On the range lands within the national forests, efforts have been made to reduce the numbers of livestock down to a point where overgrazing ceases. On many areas badly depleted and eroding, such negative action is not enough. Positive action must take its place. Reseeding the ranges to desirable grasses is therefore a prime consideration and is essential on some 13½ percent of the entire national-forest range. The question arises of what species to use, and as in the case of forest planting, there is need for information on the suitability of plants to soil type and soil fertility. Although reseeding programs are not as extensive as in the case of forest planting and reseeding on a large scale has not yet been attempted, failures and successes emphasize the necessity for investigations that take soil definitely into account. The great diversity in the soils of the semiarid regions, the extent to which alkali is present, and the degree to which soils of the western ranges have been eroded all combine to make soil an all-important consideration in range-management operations. On many sites attempts at revegetation with native species have failed, indicating the need for more drought-resistant strains, species, or hybrids of forage plants.

Water Control

Improvement of stream flow and yield of usable water is a major objective of national-forest management, yet quantitative data on the magnitude of the influence exerted by forest and range cover are meager. There are strong indications that soil conditions associated with full stands of climax vegetative types are also associated with highest infiltration of water and greatest soil stability. There is urgent need, however, to evaluate the effect on water yield of different treatments of the cover, of transpiration losses, and of temporary cover types. The effect of cover can seldom be dissociated from soil porosity, structure, fertility, humus content, and moisture relations. Fundamental studies of soil conditions are therefore essential to the proper management of the 160 or more million acres of watershed lands in the national forests that provide water for hundreds of communities and millions of acres of irrigated lands throughout the country.

Limitations to Application of Improved Technique

Timber and range management on the national forests are carried on within a framework of legal, fiscal, economic, and areal limitations and social objectives that determine the feasibility of measures to improve either the soil or its use. The more important problems of administration and local policy arise in connection with the application of biological principles within this framework.

As an example, recognition of widespread maladjustment in use of agricultural soil has led in the East to the acquisition of considerable areas of submarginal farm land. The areas doubtless should eventually be reforested, but many of the farms are occupied when acquired and the resettlement and rehabilitation of the residents constitutes a social problem. Its solution must integrate such widely divergent factors as the opportunities for part-time employment created by the national-forest purchase and development program; the condition of the soil and the possibility of continuing it in agriculture, either with or without measures for erosion control and soil rehabilitation; the income to be expected from agricultural use; the quantity of agricultural soil locally available; cost of maintaining governmental and social functions and facilities; and the presence of agricultural soil elsewhere to which the population can move.

Under existing regulations, the national forests have had to depend primarily on timber sales for silvicultural treatment of stands. The consequences of different treatments in terms of trees and soil had to be weighed against cost of logging, markets and prices, labor supply and wages, and requirements of local populations. Until the advent of the Civilian Conservation Corps, every operation had to be not only desirable silviculturally, but profitable to the timber purchaser as well.

Trends entirely separate from soil use may cause radical changes in silviculture. For example: In the White Mountains, removal of overmature, decadent, unmerchantable hardwoods to make room for thrifty young growth is good silviculture and can be done cheaply by girdling. The unsightly snags remaining, however, detract seriously from the recreational value of the area, and recent increases in recreational use justify modification of the silvicultural practice. Similar situations are likely to develop in the future, particularly in the eastern national forests.

Elsewhere, serious objection is being raised to the planting of solid blocks of coniferous species because of the poor environment for game that results. Discontinuous plantations, mixtures of species, and, occasionally, relinquishment of large areas to brush and weeds are indicated as desirable. Soil use, therefore, may depend on the proximity of heavy populations, the amount of leisure they have, and the demand for particular types of recreation.

In the tension zones between forest and grassland, analysis of the use situation must be more thorough than for either type of vegetation alone. The trend of succession of plant associations is subject to some control through cutting, grazing, and fire. The type of vegetation to be favored can be selected in the light of soil use and con-

dition on adjacent land, and the local and regional social and economic structure.

When the national forests were established, the carrying capacity of the range included had been reduced to little more than half that of its virgin condition. It has improved since, but is still 30 percent below potential productivity. Recovery could be hastened by reducing the number of livestock grazed, but heavy reduction would place an extra burden on an already sorely pressed industry. In many instances, reduction of present numbers would bring the size of the herds and flocks below the minimum economic limit. The stock, moreover, spends only the summer on the national-forest lands. For the most part, the spring, fall, and winter range is not under Forest Service control and is overgrazed. The demand for increases in number of livestock on the forests is constant, to accommodate the increased numbers put on adjacent ranges during periods or cycles of good rainfall, and to relieve pressure on this same area in dry periods.

The range should be stocked conservatively enough to avoid injury from doughts of short duration which may be expected to occur frequently. More severe droughts may require further reductions in numbers of livestock to prevent serious depletion. As numbers of livestock on the national forests are reduced, there is often increased use of outside ranges and accelerated abuse of the land. How to attain the desirable stocking on national-forest ranges without causing more severe depletion of adjacent ranges is a problem for which a satisfactory answer has not been found.

The increasing public demand for hunting and other recreation has affected range use as well as silviculture. Its influence on use of range land has been chiefly in the direction of reduction of livestock numbers to share forage with game and setting aside areas for the exclusive use of game species. There is a natural tendency among range users to direct the establishment of refuges and preserves toward the inaccessible and less favorable areas. To follow such a policy, however, tends to defeat the very purpose of game management by making hunting unavailable to a large portion of the population. Trends in hunting demand should be carefully studied to provide a sound basis for modification of range use in the future.

No clearly defined changes in present vegetative cover types are needed to increase the yield of usable water from national-forest areas. Pending the outcome of detailed studies of forest and range influences, therefore, effort should be directed toward increasing the density of existing cover and soil porosity.

The distribution and use of water, particularly in the West, is governed and controlled by very complex laws and rights with which the national forests are not concerned. Insofar as the use of water, particularly for irrigation, is involved, however, it is an element in the problems of national-forest soil use. Expansion of irrigation on land adjoining the forests may create new demands for grazing use as well as new markets for timber products, increase demand for recreational use of the forests, and attract additional dependent population. Existing timber- and range-management plans must be scrutinized in the light of the new situation.

How the Problems Can Be Solved

The body of factual knowledge upon which national-forest soil use should be based can be acquired in two ways—by carrying on studies through the Forest Service research branch, or by depending on piecemeal contributions from workers in other agencies. Much valuable information has already been contributed by outside workers, but progress in the solution of national-forest soil problems is slow and uncertain.

Intensive research on forest soils could easily employ a very considerable corps of workers, for only exploratory phases have been dealt with. Viewing expansion of Forest Service research realistically, however, it is unlikely that proposals for more than two or three soils men in each major forest region could be justified. Such a staff could be adequately financed for one-tenth of a cent per year per acre of national forests. The directed effort of this group when coordinated with the soils studies of other agencies could provide the basic data needed for rational and effective soil-use planning within a reasonable period. Concurrent studies in silviculture, forest and range management, utilization, economics, and forest and range influences are already under way at the regional forest experiment stations. The close tie between research and administration of the national forests, moreover, facilitates the adoption of improved practices as developed.

The function of the Forest Service as a land-use planning agency has long been recognized. Its organization includes divisions dealing with various land uses such as timber management, range management, recreation, wildlife management, and research, and definite provision for adequate coordination and integration of use. Supervisors of the individual forests are responsible for the solution of local problems of integration, regional foresters for State and regional ones, and the Bureau chief for those of national scope. The mechanism for close cooperation with other land-use planning agencies and with other bureaus of the Department of Agriculture interested in soil use is thus provided. What is needed, therefore, is intensification of cooperation rather than new methods or organization.

MANAGEMENT OF STATE-OWNED LANDS[3]

States are landowners because of original ownership, as in the case of the 13 colonies or Texas, or because of direct grants from the Federal Government. Land was donated to the States to be sold for the benefit of schools, colleges, and universities, for internal improvements, and for drainage of swamp lands. In most cases the land so granted lay within the boundaries of the State, but in other cases where no Federal lands existed within the State, scrip was issued which the State could locate anywhere on the public domain or sell to individuals. The area granted to States is approximately 221 million acres plus about 8 million acres of scrip land.

The purpose of these grants was not to make a landowner out of the State, but to give the new commonwealth a source of revenue. Some of the land was sold very cheaply, for States with a sparse population

[3] The following publications are cited in connection with this subject: (*92*, *181*, *255*, *436*, *444*).[4]

[4] Italic numbers in parentheses refer to Literature Cited, p. 1181.

and a meager tax base were hungry for revenue and used their lands as a means of attracting settlers. However, in some cases the Federal Government prescribed a minimum price below which lands could not be sold. This price ranged from $3 to $25 per acre, with $10 the usual amount, but in many cases it proved to be too high. Because of this and the stipulation that the land must be sold, which prevented the granting of land free under a homestead or similar policy, many States still owned enormous areas.

The administration, or rather the sale, of the donated lands has been entrusted to various offices or commissions by the States, some of them designated by the constitution. Except where minimum prices were excessive, the lands of agricultural value have been sold long ago, and these organizations are still holding the remainder for sale though the more reasonable thing to do would be to turn it over to the State for forestry or recreation, its best use. However, legal and constitutional provisions stand in the way of surrender or sale to another State department.

A new form of publicly owned land is the property reverting for taxes. This "new public domain" becomes State property in 19 States, county property in 23, and in the six New England States it reverts to the towns. There is no accurate record of the area owned by these units of government because of tax delinquency, but it probably amounts to 50 million acres. In addition to the area actually in public ownership there are many millions of acres delinquent long enough so that the State, county, or town could take title, but they refuse or hesitate to do so. Even though no taxes have been paid for many years, there is always the hope that someone will buy the outstanding certificates or the owner will redeem his property and restore the land to the tax roll. Apparently there is still a deep-seated feeling that there is something unnatural about the public ownership of land, particularly land which some private owner has lost. Every effort has been made in the tax laws to make redemption easy and the taking of title by the public difficult. Another reason for the reluctance to take title is the fact that property taxes are the chief sources of revenue for local governments, and public ownership of any kind permanently removes the land from the tax roll. This is overcome in part by granting some form of State subsidy in lieu of the former taxes whenever the State becomes the owner of the land.

However, public ownership of certain types of land is inevitable. Where prices have been reasonable all of the better agricultural land granted to the States has become private property, leaving the submarginal soil areas in the possession of the States. Land found by private owners to be unsuitable for farming, forestry, or private recreation finally reverts to public ownership because the owners do not, or cannot, pay the taxes even in States with the tax rate limited by law. The time has come when public bodies must expect to own land and administer large tracts of land unsuited to private ownership.

Before the question of proper administration can be considered it is important that the State or county obtain a valid title to tax-reverted land. This is still a moot question in most States, because tax laws are still so drawn that the owner retains rights of repossession for many years after he has ceased to pay taxes. Michigan is one of the few

States which have fixed a definite time beyond which the State's title becomes absolute. Six months after the deed is made to the State and recorded in the county where the land is situated, the title to the land becomes absolute and no suit or proceeding to set aside, vacate, or annul the deed can be instituted. New York also has set a fixed date after which the State's title cannot be contested.

Even though the property rights of private individuals are cancelled, there is still the claim of the other units of government to the same land, insofar as taxes due to them have not been paid. In Wisconsin this problem does not arise because the county bears the entire burden of tax delinquency and the property reverts exclusively to the county with no claims of the State, towns, or schools against the land except when the county sells it. In Michigan, tax-delinquent lands reverts to the State, and the interests of the local units of government are extinguished by the payment of 25 cents an acre to the county, township, and school district in which the reverted lands lie. This holds for all lands definitely reserved for State administration for parks, public hunting grounds, forests, etc., but the money received from the sale of tax-reverted land is deposited in the State treasury to the credit of the respective taxing units in proportion to their tax equities in the land sold.

After the lands are securely in the hands of the county or State, a definite policy of administration is imperative. Michigan tried a program of getting the land back on the tax roll by a homestead policy similar to that of the United States, but much of the homesteaded land came back via the tax-delinquency route. Submarginal land is submarginal even if given away. The homestead plan was repealed in 1935. Millions of acres were also sold, which induced extensive speculation, but sale was not mandatory and gradually a policy of reserving riparian and other land for forests, public game preserves, and parks has replaced wholesale disposal. Land reserved for conservation uses is deeded to the director of conservation. New York also has placed tax-reverted lands under adequate administration as forests and parks, but in recent years has acquired practically all of its forest and recreational lands by direct purchase.

Because the best use for tax-reverted land is for forests and recreation, requiring, as a rule, large areas, administrative talent, and costs beyond the means of small units of government, it is generally considered the best policy to have lands revert to the State rather than to the county or town. If the arguments for this are valid, drastic changes will have to be made in the legal set-up of some 29 States. On the other hand, Wisconsin has started on a program of zoning the land of the problem areas through county ordinances and administering tax-reverted lands through county action. Counties can take tax title after 5 years of delinquency, block up the lands into county forests by exchange with private landowners or public agencies, and enter the land capable of forest development under the forest crop law. County forest land approved by the State conservation department assures a distribution of 10 cents an acre to local units of government (40 percent to towns, 40 percent to school districts, and 20 percent to the county) and an additional 10 cents an acre to the county directly for forest administration. Forestry work is done in

close cooperation with the State conservation department. The State is to receive 50 percent of the stumpage value when the timber is harvested. Zoning by merely prohibiting agriculture and allowing forestry in restricted districts is negative, but the forest crop law actively stimulates the development of both private and county forests in the areas set aside for this land use. In September 1937 there were 156,000 acres of privately owned land and 1,700,000 acres of county-owned land entered under the forest crop law in Wisconsin, and over 5,000,000 acres closed to agriculture by rural zoning ordinances in 24 northern and central counties.

Proper State administration requires that the land be placed under the jurisdiction of a capable branch of the State government, such as the usual conservation department, with power to dispose and administer all State-owned lands. Price limitations should be removed so that land capable of private ownership can be placed in such ownership. On the other hand, there is nothing to prevent States from adopting the leasehold and leasing land to individuals or corporations. This is preferable in oil and mineral lands, certain types of recreational land, and grazing land. Where public and private holdings are intermingled, administration can be facilitated by exchanges, and the State should cooperate with public and private owners in such worthy enterprises as grazing districts. For purposes of proper administration the "donated land" now under the jurisdiction of various commissions, etc., should be turned over to the conservation department to be blocked up with other land for various uses. If direct transfer is not desired, the land may be sold to the administering agency at a reasonable price and the money placed in the school fund.

When land comes to the administrative body through tax delinquency it should be classified either through a general economic land survey of the entire problem area or parcel by parcel as the title of the State becomes complete. Tax-reverted land, however, may range from city lots or platted lots on lake shores to farms and cut-over areas. Those parcels situated in organized municipalities can either be sold or perhaps turned over to the city or village for administration with payment to the State to extinguish the State's interest in the property. Some of the lands not in municipalities may be sold, but the remainder should be deeded to the administering body upon classification. One difficulty is the scattered nature of tax-reverted land, with parcels too small for forests or parks and difficult to administer. This calls for exchanges with public and private owners or sale. Sometimes a piece of tree-covered land can be sold to a farmer for a wood lot. Once blocked up, the area should be dedicated to the most efficient use and expenditures for administration and maintenance gaged accordingly. The final step, and by no means the easiest, is the reorganization and readjustment of local governments to meet the new situation.

PUBLIC PURCHASE OF LAND

In recent years the purchase of land by public agencies has come to be regarded as an effective means for correcting maladjustments in land use. It is only one means, however, and the question arises as to the nature and extent of the contribution that a program of public

acquisition of land might reasonably be expected to make to the solution of our national land-utilization problems, including the restoration and conservation of soil and the rehabilitation of rural families. Measures of the kind enumerated in this and the following articles should be fully utilized, and their availability should be one of the first considerations in delimiting the scope and character of a public acquisition program.

Starting from the premise that public purchase should be utilized to effectuate adjustments in and control of land use only to the extent that alternative measures cannot be effectively utilized, the problem remains as to what further limitation can be made in the conditions under which public purchase of land may be regarded as a desirable procedure.

Perhaps an answer to this question may best be sought by an examination of the scope and character of the Federal purchase program initiated in 1934 by the Land Policy Section of the Agricultural Adjustment Administration, which involved the establishment of 98 agricultural land-use adjustment projects.

Seventeen of these projects are located in the northeastern part of the United States and in Ohio and Indiana. Within the area embraced by these projects approximately 278,000 acres will be acquired. These areas, although different in many respects, present in common a history of occupation and gradual abandonment extending over a considerable period. Rough topography, poor soil, and shifts in type of agriculture have contributed to this abandonment. Within these areas are stranded families, and into these areas, in periods of depression, families in distress naturally gravitate, thus tending to reestablish or perpetuate conditions that contribute to the deterioration of the lands and the families that occupy them. At the same time, these isolated families place upon the general community an unnecessary burden of public cost for the maintenance of roads, schools, and other public facilities and services.

The question presented by areas of this type is the extent to which the public purchase of land may be effectively utilized to bring about desirable adjustments. Attention has already been called to the principle that public acquisition should be supplemented by corollary programs if the best results are to be achieved. For example, unless the establishment of a national forest, a national park, a national game refuge, or some other special objective is involved, it may well be questioned whether it is desirable for the Federal Government to undertake extensive purchases of abandoned and semiabandoned lands of the type under consideration, particularly with a view to blocking in large areas. As an alternative, a program of Federal acquisition might be inaugurated involving the acquisition of occupied holdings, primarily those occupied by destitute or isolated families, with a view to assisting in the reorientation of the population and the conversion of the lands involved either to a less intensive type of agriculture or to appropriate nonagricultural use or uses. The feasibility of such a program would obviously rest largely upon the extent to which it is supplemented by a State zoning program under which, with proper limitations, all lands within the area would be reserved for the particular type of use for which they are adapted, excluding

such lands from occupancy for other purposes. Equally essential is the recognition of the importance of a parallel program to effect the relocation and rehabilitation of families displaced by Federal purchase of the lands they occupy. Thus there emerges a threefold program embracing public purchase and conversion of lands to uses for which they are best adapted, State or county zoning of lands against occupancy for uses for which they are physically and economically unadapted, and the relocation and rehabilitation of the population involved.

Eighteen of the agricultural land-use adjustment projects, involving the purchase of approximately 1,357,000 acres, are located in the cut-over regions of the Lakes States and in Florida, Washington, and Oregon. Farm and squatter families are thinly dispersed over these second-growth, cut-over, and burned-over areas. These families occupy the more level lands and remote spots along the streams in the hilly sections, which give deceptive promise of fertility and adaptability to cultivation. The soils are generally poor. The isolation of the families and the poverty of the soil reproduce the familiar conditions—low family income and correspondingly low standards of living, and inadequate public facilities and services combined with high costs of the services provided.

In the projects located in the Lakes States and in the Northwest, it has been possible to acquire tracts occupied by families in relatively small acreages, since the adjacent lands are generally in Federal or State ownership. Thus it has been possible to bring under public control large areas of land unsuited to agricultural use merely by acquiring the lands necessary to permit relocation and rehabilitation of isolated families. In Florida, on the other hand, most of the land is in private ownership. In the absence of a zoning program in that State, it has been necessary to buy a considerably larger proportion of unoccupied land than has been the case with projects located in the other areas. This situation invites consideration of the desirability of requiring States to enact zoning and other types of appropriate legislation as a condition prerequisite to the establishment of Federal purchase projects for the purpose of effecting adjustments in the use of land for agricultural purposes.

East of the Great Plains States there are 40 additional agricultural land-use adjustment projects, including projects established in eastern Oklahoma and Texas. These involve the purchase of approximately 1,147,000 acres. Sheet and gully erosion, consequent upon improper farm practices or the cultivation of lands either too steep or too dry for the production of cultivated crops, is characteristic of the lands embraced by these projects. Generally speaking, housing and sanitary conditions are poor and social and public facilities are inadequate. Family incomes are low. The family diet often falls below the minimum requirements of dietary adequacy. The population in these areas is relatively denser than in areas previously discussed. Consequently, adjustments to effect the conservation of the land and the relocation and rehabilitation of the population are more difficult to achieve.

It is entirely possible that a program of farm reorganization effectuated through the purchase and lease of the lands necessary for the

establishment of farms of appropriate size may represent the best approach to the solution of problems presented in areas of this type. It is not essential to such a program that lands be acquired by the Federal Government for lease to farm operators. If the adjustment program is properly planned, it might well be effectuated by providing long-term credit on terms which would permit individual operators to acquire the lands necessary for the efficient organization and operation of their farms. Essential to any such program, whether effectuated through Federal purchase and lease or through Federal credit extended to individuals, is a Federal program for the relocation and rehabilitation of families displaced from the area. The carrying out of such a program of relocation and rehabilitation will obviously involve the use of Federal funds, either for the direct purchase of the lands required or for the extension of the necessary credit to the displaced families.

In the Great Plains States and in States west of the Great Plains, excluding Washington and Oregon, there are 23 land-use adjustment projects in which approximately 4,013,000 acres are being acquired. These projects are located in areas of insufficient rainfall. Conservation of water and its proper distribution are primary requirements of these lands. A basic problem of land-use adjustment is the need of bringing the use of range land for grazing under adequate control with a view to adjusting use to carrying capacity under present conditions of range depletion. In some areas the situation is so critical as to present the alternative of continuing the livestock industry on a reduced scale or completely depleting the range, with consequent destruction of the cattle and sheep industry. In such areas it has proved possible, through these projects, to carry out a program for the control of the range that involves a minimum of Federal purchase. Such a program is facilitated through the integration of the Federal purchase program with the program for the utilization of the public domain. Private lands, interspersed with Federal lands, may then be brought under control by encouraging the leasing of privately owned and State-owned lands by cooperative grazing associations. These associations, in turn, secure the use of Federal lands by agreeing to sound principles of range management and utilization under a program of conservation supervised and controlled through the Federal and State Governments.

The projects described above and the problems of adjustment involved suggest the major principles upon which a Federal program of purchase should be based:

(1) The purchase of land should be projected as a long-time program.

Both the magnitude of the problems and the character of the adjustments involved require a program extending over a period of years. The magnitude of the program is illustrated by the fact that there are 454,000 farms that should be retired from arable farming, according to a report of the National Resources Board (*433, p. 181*). These farms comprise 75,000,000 acres. The retirement of land from arable farming involves detailed and careful planning in order to effect adjustments in the pattern of land use that will, in fact, improve the economy of the area. Changes in the pattern of land occupancy, the organization of farms that are not retired, the location of roads, the distribution of schools, adjustments in the tax base, and so on, must be worked out as a basis of the

purchase program. The adjustments to be effectuated by public purchase must be integrated, moreover, with the adjustments in use and management of other lands already in public ownership, and of lands remaining in private ownership.

(2) The purchase program should be directed to the correction of maladjustments in the use of land for agricultural purposes, including grazing.

The program should be restricted largely to the purchase of land employed in agriculture and occupied at the time the land is acquired. The purchase of intervening or adjoining tracts not falling within these categories should be held to a minimum. Such tracts should be acquired only when their purchase will definitely facilitate the efficient operation and conservation of the area as a whole.

Tracts should not be acquired simply because they are "submarginal for agricultural use" or "not primarily suitable for cultivation." For example, forest, cut-over, and swamp lands, and lands of a similar type, would not generally fall within the scope of the purchase program.

(3) The purchase program to effectuate agricultural land-use adjustments should be differentiated from other programs involving the public acquisition of land.

There are various public benefits to be attained by the acquisition of land for specific purposes, such as forest, recreational areas, game refuges, parkways, etc. Programs of purchase directed to these specific ends, while amply justified from the standpoint of public welfare, should be clearly differentiated from a program designed to correct maladjustments in the use of land for agricultural purposes.

(4) The Federal program of purchase to effect adjustments in the use of land for agricultural purposes should be closely integrated with other Federal and State programs of land conservation.

As has been pointed out, there are numerous spheres of action within which reliance must be placed upon the States to effectuate desirable adjustments in the use of land. Passage of enabling legislation for the establishment of cooperative grazing associations and zoning of lands against uses for which they are unadapted are illustrative of lines along which a Federal purchase program should be integrated with State programs.

At the same time, the agricultural adjustment purchase program should obviously be integrated with Federal programs for flood control, for erosion control, and for the regulation or control of agricultural surpluses.

Within and adjacent to national forests, also, the purchase of occupied land in connection with an agricultural adjustment purchase program should provide a basis for integrating the national-forest program with the agricultural adjustment program, particularly in those areas in which there exists an intermediate zone between forestry and farming that provides a basis for the development of a farm-forest economy for the area.

(5) The purchase program should not include the acquisition of land for the purpose of blocking up large areas merely to secure organized control of the land.

By integrating the Federal purchase program with related Federal and State programs of conservation, securing the enactment of appropriate State legislation, and encouraging the adoption of appropriate credit policies on the part of Federal and State agencies, desirable regulation of land use may be effected without resort to the procedure of blocking up large areas in Federal ownership.

(6) The purchase program should be supplemented by a program for the development of lands acquired.

The development undertaken should be with specific reference to the plan of management and use of the lands and to the specific requirements of the agency undertaking their administration. Expenditures for development prior to the assignment of projects to an agency for continuing administration should be

restricted to improvements of a relatively permanent nature as distinguished from expenditures for operation or maintenance.

(7) The program of purchase should be supplemented by a program for the relocation and rehabilitation of displaced families.

A program directed primarily to the acquisition of lands in agricultural use and occupied at the time of purchase will encounter almost insurmountable obstacles unless supplemented by a program to give guidance and assistance in the relocation and rehabilitation of the families occupying the lands acquired.

(8) In areas not primarily employed in agriculture, including grazing, Federal purchase of scattered tracts utilized for agricultural purposes should be undertaken only when the lands not acquired are wholly of a physical character that would exclude them from any reasonable probability of settlement or where the lands not acquired are subject to control by other agencies or measures.

Under title III of the Bankhead-Jones Farm Tenant Act, passed by the first session of the Seventy-fifth Congress, and approved by the President July 22, 1937, provision is made for a program for the retirement of submarginal land. This program provides a basis for effecting adjustments in the use of land for agricultural purposes in conformity with the principles outlined above. Under title III of the act the Secretary of Agriculture—

is authorized and directed to develop a program of land conservation and land utilization, including the retirement of lands which are submarginal or not primarily suitable for cultivation, in order thereby to correct maladjustments in land use, and thus assist in controlling soil erosion, reforestation, preserving natural resources, mitigating floods, preventing impairment of dams and reservoirs, conserving surface and subsurface moisture, protecting the watersheds of navigable streams, and protecting the public lands, health, safety, and welfare.

To carry out the provisions of title III there is authorized to be appropriated "not to exceed $10,000,000 for the fiscal year ending June 30, 1938, and not to exceed $20,000,000 for each of the two fiscal years thereafter." Under this program projects have been established involving the acquisition of approximately 1,600,000 acres of land during the fiscal year ended June 30, 1938. These purchases are confined to the Great Plains region where problems of land conservation and conditions of distress among the dependent population are especially critical because of recurrent drought in the affected areas. Purchases in the Great Plains region are to be supplemented during the fiscal year 1938 by the acquisition of a limited number of tracts, essential for the efficient use and administration of lands already acquired in the projects previously established under the program inaugurated by the Land Policy Section of the Agricultural Adjustment Administration in 1934.

The foregoing principles have been outlined with reference to a program of Federal acquisition. Because of the broad geographic character and complexity of a purchase program designed to effect adjustments in the use of land for agricultural purposes, it is believed that State programs of purchase will, of necessity, be too limited in scope to meet the problems involved. On the other hand, as has been pointed out, there is a broad field of State action that is essential to effecting and perpetuating the adjustments sought through Federal purchase. The success of a Federal purchase program is, therefore,

contingent upon the cooperation and collaboration of the State in which the purchase program is carried out. State purchase programs are likely to achieve their most effective results through the acquisition of land for specific uses such as game refuges, forests, and recreational areas. The development of strong conservational agencies within the various States should also contribute to the effective administration of lands acquired by the Federal Government that may subsequently be transferred to the States for administration.

HOW FAR the Nation and the States can go in applying direct remedies for soil misuse on privately owned land is a question that is now sharply in the forefront of national thinking. Certainly there is no one panacea, and certainly education alone is not enough. This article considers the possibilities and limitations of such measures as rural zoning, cooperative action in grazing associations, the soil conservation districts laws, resettlement of distressed farm families, revisions in reclamation policies, and changes in landlord-tenant contracts. Some of these measures are already being successfully applied. All are in the stage of question and debate natural in a democracy.

The Remedies: Policies for Private Lands

By George S. Wehrwein, Clarence I. Hendrickson, M. H. Saunderson, Philip M. Glick, Carl C. Taylor, Francis R. Kenney, *and* Marshall Harris [1]

RURAL ZONING

ZONING is a means by which the police power is used to promote the proper use of land under certain circumstances. The police power traditionally resides in the State, and the power to regulate land uses by zoning is usually delegated to minor units of government, such as towns, municipalities, and counties, through an enabling act that specifies the powers granted and the conditions under which these are to be exercised.

Although specific ordinances and regulations have been and will be declared unreasonable, zoning of urban land is well established and has stood the test of constitutionality. Urban land is zoned by ordinances that divide the city into districts and specify the permitted and prohibited future uses of the land within each district. Courts have declared that cities have the right to exercise public control over private land in the interests of safety, health, morals, and public welfare, concepts that include harmonizing land uses, relieving conges-

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tion, and stabilizing property values. These regulations often cause hardships to private landowners by circumscribing the uses to which the land may be put and by lowering the future income-producing power of the property. Unlike losses resulting from exercise of the power of eminent domain, those due to the exercise of the police power are borne by the private landowner; if compensation is granted it is only through generosity on the part of the State.

The police power, however, is not unlimited. Its bounds are set by the fifth and fourteenth amendments to the Federal Constitution which provide that no one shall be deprived of life, liberty, or property without due process of law.[2] The limits which these constitutional provisions place on rural zoning will be determined by the courts in cases brought before them. To be valid, every rural zoning ordinance must meet the test of constitutionality as decreed by the courts. It will be necessary to show that regulations placed on the use of land under an ordinance actually promote the objectives for which the police power may be invoked and that the burdens placed on the landowner are reasonable.

The power to zone the land outside incorporated places was granted to all counties in Wisconsin through a State Enabling Act in 1923. County zoning under this act was for the purpose of controlling suburban land and setting up residential, commercial, and industrial districts adjacent to cities; but an amendment to the Enabling Act, in 1929, inaugurated rural zoning by permitting the zoning of land for agriculture, forestry, and recreation. The Michigan Enabling Act of 1935 added soil conservation and water conservation, thus broadening the land-use control features as given in the Wisconsin act.[3]

It should be noted that rural zoning was not the first means of controlling the use of agricultural land. Weed laws, corn-borer control, and health and sanitary regulations are all illustrations of the earlier legislation. They differ from zoning in two respects. Most of these acts are State laws and are enforceable throughout the entire State. Zoning is delegated to specific units of local government and is permissive, not mandatory. It is thus a local function depending for its success on the willingness, intelligence, and determination of the people of a given town or county to place and enforce regulations upon the use of land. This is both the strength and weakness of zoning. Furthermore, zoning regulations under the enabling acts as adopted cannot be made retroactive. Land uses established before the ordinance was passed must be permitted to continue even though they are not in conformity with the provisions of the ordinance. However, nonconforming uses once discontinued usually cannot be reestablished, and eventually an entire district may consist of uniform conforming land uses.

It is significant that in northern Wisconsin, where zoning for agriculture, forestry, and recreation had its inception and has made the most progress, is an area where only about one-fifth of the land is in established agriculture and a much smaller proportion in private

[2] For a discussion of the police power, see The Soil and the Law, p. 296.

[3] The following States have laws which are intended to permit rural zoning in all counties: California, Indiana, Michigan, Pennsylvania, Washington, and Wisconsin. In addition, Tennessee has a law that provides for rural zoning in certain counties. No strictly rural ordinances have been adopted outside of Wisconsin. Several county zoning ordinances are in force regulating urban and suburban uses of land in a number of States.

recreational land uses. The small tracts of remaining merchantable timber are destined to become cut-over land as fast as the timber can profitably be removed. Roughly 75 percent of the area is not in productive use but is idle cut-over land, much of it tax delinquent or reverting to county ownership. Since the future use of this land is still to be determined, the future utilization and promotion of the right use of the soil may be directed by zoning. The nonconforming users scattered throughout the 5 million acres of land in Wisconsin restricted against agriculture occupy about 3 percent of this area. With a proper land-purchase program the settlers can be assisted in locating on better land, and thus in time the nonconforming uses will be eliminated.

Rural zoning in Wisconsin was started primarily to control future settlement by keeping farmers from selecting land remote from established communities and thereby creating demands for new highways, schools, health services, etc., the cost of which would fall upon the taxpayers in the established portions of the area, upon the county, and, through the system of State aids, upon the taxpayers throughout the State. Zoning to prevent excessive governmental costs is so directly in the interest of public welfare that it can be justified even though it does nothing to protect settlers from purchasing submarginal land or to promote the best use of land. A county consisting of uniformly excellent farm land might wish to regulate the future location of farm residences for the purpose of keeping the community compact and minimizing school and road costs. In such cases, zoning can become an effective measure for controlling and directing the flow of agricultural settlement, just as the purpose and procedure followed in setting up commercial districts in urban and suburban territory aim to control the location of business enterprise.

However, local people had a second motive in zoning submarginal land—to make it impossible for anyone to settle on such land. In this form zoning becomes land classification plus the power to force the owner to use his land in accordance with the classification. Approached from this standpoint, a classification of the agricultural land might be made and districts based upon the grades of farm land set up, with an ordinance granting permission to settle only on the first-grade land. The other grades might conceivably be restricted until the increase in settlement made it desirable to open one or more of the next lower grades of land for farming.

Zoning may also be found a desirable instrument in areas where considerable farm abandonment has taken place. Abandoned land is peculiarly subject to undesirable settlement, especially where buildings remain and some land has been cleared. This is particularly important during periods of depression. Many county or other local governmental units found public costs increased several fold in the years following 1930 by the resettlement of abandoned farms. Because of the poor quality of the land, many families seeking refuge on it have not become self-sustaining but have simply increased the relief load of localities least able to bear the additional burden. Zoning areas of abandonment against settlement would prevent this added relief load and other costs of local government.

The recreational zones as set up in the Wisconsin ordinances are primarily for the purpose of directing the use of land and not to reduce

public costs. Since there is no restriction against residential uses of land, roads and schools must be provided no matter how small the population. Recreational districts are designed to promote the highest use of riparian land by excluding conflicting uses, chiefly agricultural, because clearing the land destroys the wilderness aspect of lake and stream and creates a fire hazard. Forestry is permitted, and as long as this means reforestation it is in harmony with the purpose of recreational districts; it may be desirable later to modify present ordinances to prohibit the cutting of trees within a certain distance of the shores of lakes and streams. The limitations on land use found in urban ordinances to control population density and promote sanitation in cities have not yet been incorporated in the regulations for the recreational districts in the Wisconsin rural zoning ordinances. These aspects of land-use control are now being regulated directly by the State Board of Health or by private deed restrictions in Wisconsin, but such regulations could easily be made a part of a recreational district ordinance.

Insofar as forests control erosion, this menace is removed from the 5 million acres of land in forest and recreational zones in Wisconsin except for the areas where nonconforming uses remain. Zoning for the same reason protects the streams and lakes against silting or pollution from agricultural sources, and tends to keep the waters in the proper condition for aquatic life. The restricted districts also provide ideal conditions for wildlife, game, and recreation. An amendment to the Wisconsin Enabling Act in 1935 for stream-bank zoning was aimed at regulating urban and industrial uses along water courses, but it appears to be broad enough to permit restrictions against land clearing and uses that would affect the amenities of stream and water channels. This feature of the act might be of considerable importance for flood-plain zoning.

Land-use regulations that do not go beyond restricting land uses merely promote the right use of land by prohibiting the wrong use. Unless something is done to stimulate or induce the right use in the restricted districts, zoning is merely negative. Forest zones must be adapted to the needs of forestry or the land will not be used for this purpose, and the restrictions may be considered unreasonable. If land is to be restricted to forestry the areas should be large enough to block up into forest units. Provision should be made for the exchange of publicly owned land for privately owned land and for the purchase of the holdings of isolated settlers to remove nonconforming land uses. Another positive action necessary to stimulate private forestry is to adjust the tax burden on forest land by special forest-tax legislation similar to the Wisconsin forest crop law, which provides for a small tax payment annually and a severance tax when the timber is harvested. The only other alternative to setting up conditions under which private forestry can thrive is public forests. In fact, public ownership is the only alternative for forest land on which private commercial forestry is unprofitable; and protection or recreational forests must by their very nature be publicly owned.

Zoning appears to be least effective in promoting the best use of land on already existing farms because of the nonretroactive feature Erosion control would be difficult through zoning. In the first place

land-use practices and the conditions under which land is used are as important in controlling erosion as the kind of use. While urban and suburban zoning often set up conditions under which the different uses may be carried on, a similar procedure does not appear as suitable for erosion control in agricultural areas. The land-use practices and the conditions under which land may be used for crops or grazing vary so greatly even from farm to farm that it would be difficult to set up districts within which uniform regulations could apply. In the second place, if the nonretroactive feature were continued, zoning would not be effective in bringing about a change in a land use established on the farms before the ordinance was passed. It might, for example, prevent a landowner from denuding a wooded slope, but it could not compel him to reforest the land if the established use were pasture or cultivated crops. The soil conservation district set-up or the direct use of the police power by the State would probably be more effective.

The application of zoning to rural areas is in the stage that urban zoning was in 20 or more years ago. It will probably have to endure the same growing pains before it becomes an effective instrument for the public control over private land. It will have to develop its own technique for enactment, administration, and interpretation of zoning terminology, as, for instance, nonconforming uses. As a delegated function to counties and towns it offers a democratic means of control and direction of land use; but it must be recognized that it is also subject to the same limitations as all other acts of local government. Zoning should be adapted to local conditions. So far rural zoning has developed only in marginal areas, but it is being proposed for older, well-settled agricultural counties. Here the suburban and rural types of zoning merge. Zoning to control riparian land along streams and lakes for recreation, flood prevention, and erosion has great, but as yet unexplored, possibilities. Finally, zoning should not be viewed as static; with changing social and economic conditions boundaries of districts and the provisions for land-use control should be flexible.

COOPERATIVE GRAZING ASSOCIATIONS

In a number of Western States, including North Dakota, South Dakota, Wyoming, Colorado, Idaho, and Oregon, and especially in Montana, cooperative grazing associations have been organized, either under legislation granting special authority for their incorporation or under existing legislation for the incorporation of cooperatives. This type of association as it has developed in the northern Great Plains is a stockmen's cooperative business organization which attempts to do the following things:

(1) To organize the management and use of an area in which the members have a community of interest and are willing to assume the responsibility for cooperative administration and use.

(2) To centralize all leasing of lands of the grazing area in the organization, and to obtain leases at rental rates based on carrying capacity for as long a term as possible upon all lands of the area not owned by members.

(3) To work out plans for range improvement, management, and use of the area.

(4) To develop a set of rules and procedures as the basis for distributing grazing privileges to members and for conducting the business affairs of the association.

It can be seen that the functioning of the grazing association as a measure for the improvement of land use rests upon private contract rather than upon invoking the police powers of the State for control over the use of privately owned lands. Its success as a land-conservation measure rests upon two premises—that experienced stockmen can agree to apply unbiased information relative to the use limits and management needs of grazing lands, and that they can act effectively upon such information when the adequate legal and administrative machinery is provided for organized cooperative operations as opposed to a competitive race for individual strategic advantage in the control of grazing lands of diverse and intermingled ownerships.

The original Montana act of 1933 established the legal authority and outlined the policy and the principles for the organization and operation of cooperative grazing associations. The need for administrative leadership soon became apparent, however, for smoothing out overlapping district boundary problems, for developing uniform rules and operating procedures, and for arbitration for the diverse problems arising out of the operations of the associations. This need was met by the 1935 Montana Legislative Assembly through the creation of a commission with a full-time paid administrative officer. The commission was given the power of approval or disapproval over grazing association organizations, and has the power to act as a fact-finding and arbitration board in problems of rights between associations and among the members of an association. The commission has undertaken to develop, through the association bylaws, certain policies and standards for association rules, regulations, and operating procedures. While it would apparently be legally feasible to organize a grazing association under a general cooperative act, the Montana experience has indicated the desirability of a special statute to define rather clearly the nature and objectives of the association, to outline the plan of the articles of incorporation, and to define the powers of the organization.

It is clearly evident that this type of organization has at least made a start in filling an urgently felt need for some new procedure in grazing-land control and management. By August 1936 there were 27 associations in active operation in Montana, and others in process of organization. These 27 associations had under cooperative control a total of 6,538,000 acres of grazing land. This total acreage was in the following ownerships: Public domain, 2,271,000 acres; privately owned (resident and nonresident), 2,029,000 acres; Federally repurchased lands, 1,145,000 acres; county owned, 482,000 acres; State owned, 307,000 acres; corporate owned (railroad and finance companies), 304,000 acres. These various ownerships are of an intermingled nature, and the State cooperative association affords the necessary business and legal machinery to bring them all under organized management for the area. The ranch properties under individual-operator ownership or lease totaled 2,533,000 acres. This was the land used for winter feed production and winter pastures. These associations varied in size from one of five members, controlling 46,000 acres of grazing land, to one of 287 members, controlling 1,752,000 acres of grazing land. The most desirable size of a cooperative grazing district, from an economic and administrative viewpoint, is

limited by the existence of natural or artificial barriers and community interests.

One of the first and most urgent needs of these associations has been a grazing survey of their area, to serve as a basis for a plan of management and use. The recently planned cooperative western range survey should eventually meet this need. The associations have estimated the carrying capacity of their range area for the grazing period of 6 to 8 months on the basis of past experience. This has proved difficult to determine accurately since frequently some parts of the area have been used in the past as open range with the intensity and season of use indeterminate. The estimated grazing capacity of the range area has then been related to the capacity of the total ranch properties of members for winter feed production and winter pasture. This gives a ratio of wintering capacity to the grazing capacity of the range area, and this ratio is used as a basis for determining the winter feeding capacity of the individual ranches as a basis for the issuance of grazing permits to members.

Preliminary plans for range management and improvement have been instituted by a number of these associations. These plans include such factors as estimated animal-unit months of feed available on a sustained-yield basis, for the various divisions of the area; water development for better utilization of the area; and assignment of different divisions of the area to use for sheep, cattle, and horses on the basis of natural suitability. Some of these associations are operating on the basis of individual allotments to members, while others are grazing the entire area, or the parts of it used by the same kind of livestock, in common. From the viewpoint of individual ranch organization, there appear to be good reasons why allotments are desirable. This may not make for as efficient a plan of management and use of the entire grazing area, however, and may take away some of the incentive for conservative rates of use.

The more important aspects of cooperative grazing associations from the viewpoint of agricultural conservation appear to be:

(1) They are set up under an act which states their primary purpose to be the conservation and improvement of grazing lands.

(2) Cooperative operation in the use of the grazing lands of the area creates a mutual interest in improved management.

(3) It is probable that new management methods for the purpose of effecting range conservation practices for the area can be introduced more readily through the association than through individual operators.

(4) The association, through its business organization, is in a stronger position to use legal means to combat trespass than is the individual.

(5) The collective-bargaining strength of the association aids in obtaining better lease terms on its land as to both duration and rates, and the cooperative organization affords better business facilities for negotiating with the many hundreds of scattered landowners with whom some of the larger associations have had to deal.

In areas where there is a large percentage of public domain or lands purchased by the Farm Security Administration, local cooperative grazing associations provide a means of regulating the use and putting into effect the policies and land-conservation programs of agencies charged with the jurisdiction of federally owned grazing lands located outside of national forests. The value of cooperative grazing associations in planning the management and use of grazing areas which

include federally owned lands and assisting and advising with the administration of such lands under Federal jurisdiction has already been recognized through the execution of agreements or leases with such associations by the Division of Grazing, Department of the Interior, and the Farm Security Administration, Department of Agriculture.

While the cooperative grazing association is a new institutional development which may of itself play an important part in the future agricultural adjustments in the western Plains region, it may bear a complementary relationship to other measures designed to further adjustments and conservation in the use of the resources of this region. The public acquisition through purchase and tax default of lands now in uneconomic uses, the restraining of certain uses of privately owned lands through rural zoning, and the correlating of Federal and State programs of agricultural conservation with the goals and procedures of the cooperative grazing association, will strengthen and vitalize this recent development in the field of producer cooperation.

SOIL CONSERVATION DISTRICTS LAWS

In recognition of the seriousness of the national erosion problem, the Congress of the United States, in an act approved April 27, 1935, directed the Secretary of Agriculture to establish a Soil Conservation Service in the Department of Agriculture to conduct a comprehensive national program for the control of soil erosion. Under this statute the Soil Conservation Service is carrying on operations in 175 demonstration areas in 45 States, directing the work of 374 Civilian Conservation Corps camps, and conducting cooperative erosion-control studies at some 26 agricultural experiment stations.

The problem of erosion cannot be solved adequately, however, by work in isolated areas alone. Unless State legislation provides a mechanism by which farmers can organize themselves for cooperative action to apply on their lands the erosion-control practices that they observe on the demonstration projects of the Soil Conservation Service, the full benefits of the Federal program cannot be realized. The price of success in this activity is the relatively uniform application of erosion-control practices to all lands within a watershed or other naturally bounded area.

Because of this great need for State legislation, Congress has authorized the Secretary of Agriculture to require the adoption of suitable State legislation as a condition of his spending Federal money in any State for erosion-control work. Under this provision members of the Department of Agriculture worked with representatives from a large number of States, to prepare the Standard State Soil Conservation Districts Law, which President Roosevelt, on February 26, 1937, recommended to the 48 State Governors for submission to the State legislatures.

What the Standard Act Provides

The act provides a procedure by which soil conservation districts may be organized, such districts to be governmental subdivisions of the State, and to exercise two types of powers:

(1) The power to establish and administer erosion-control projects and preventive measures, including financial and other assistance to farmers carrying on such work on their lands.

(2) The power to prescribe land-use regulations in the interest of the prevention and control of erosion, such regulations to be first submitted to local referendum and, if approved in the referendum, to have the force of law within the district.

The act establishes a "State soil conservation committee" which has power to define the boundaries of each district, to encourage the organization of districts, to bring about an exchange of information and experience among the districts in the State, and to coordinate the several district programs "so far as this may be done by advice and consultation." Each district is an independent unit and is not subject to the control of the State committee. The act provides that the State committee shall have not less than three nor more than five members, and that these shall include the State director of extension, the director of the State experiment station, and the State conservation commissioner or commissioner of agriculture, if there are such officers in the State. The committee is authorized to invite the Secretary of Agriculture of the United States to appoint one person to serve as a member of the committee.

The procedure of organizing districts is as follows: Any 25 land occupiers may petition the State committee to establish a district. The act defines "land occupier" to include any person or corporation holding title to or in possession of lands, as owner, lessee, renter, tenant, or otherwise. The committee is required to hold a public hearing on the petition, to define the boundaries of the proposed district, and then to submit, to all land occupiers living within the boundaries defined, the question of whether the district should be created. No district may be established unless a majority of the votes cast in the referendum are in favor of it.

Each district is to be governed by a board of five supervisors, two of whom are to be appointed by the committee, and three to be elected by the land occupiers of the district. Each supervisor holds office for 3 years, and receives no compensation other than expenses necessarily incurred. A paid staff may be provided for each district.

When organized, each district will have power to do research in erosion control; to conduct demonstrational projects; to carry out preventive and control measures; to enter into contracts with farmers and give them financial and other assistance; to buy lands for retirement or for project purposes; to make loans and gifts of equipment, machinery, seeds, etc., to farmers; to take over and operate State and Federal erosion-control projects; and to recommend land-use plans for soil conservation. These powers can be carried out upon private lands only with the consent of the owner.

In addition to the powers above listed, the supervisors of each district may formulate an ordinance prescribing land-use regulations for soil conservation. Such regulations cannot go into effect, however, until after they have been submitted to a referendum of land occupiers and approved by a majority of the votes cast. The regulations may be amended or repealed, but again only after the question has been submitted to a referendum. These regulations may include provisions requiring engineering operations such as construction of

terraces, check dams, etc.; requirements for particular methods of cultivation, such as contour cultivating, lister furrowing, strip cropping, planting of trees and grasses, etc.; specifications for cropping programs and tillage practices, including rotations; and the requirement that steep or otherwise highly erosive land be retired from cultivation.

Failure by land occupiers to observe the regulations is punishable by fine as a misdemeanor. In addition, the supervisors may file a petition with the local courts asking the court to order the land occupier to observe the regulations. Such a court order may provide that if the land occupier fails to comply with the regulations, the supervisors may go upon his lands, do the necessary work, and collect the costs from the land occupier.

In any district that adopts land-use regulations, the act requires that a board of adjustment be established. Upon petition of the land occupier, the board of adjustment is authorized to permit variances from the land-use regulations in cases where application of the strict letter of the regulations would result in "great practical difficulties or unnecessary hardship." Decisions of the board of adjustment are subject to review in the local courts.

Districts are authorized to cooperate with one another, and all agencies of the State are directed to observe, on lands they are administering, all applicable land-use regulations.

After a district has been in existence for 5 years, land occupiers may petition for discontinuance of the district. The question of discontinuance must be submitted to a referendum, after which the affairs of the district will be wound up unless a majority of the votes cast are in favor of continuance.

Funds to finance the operations of the districts will come from two sources: (1) Direct appropriations out of the State treasury, to be divided among the districts by the State committee, and (2) grants-in-aid made, either directly to the districts or through the State committee, by the Soil Conservation Service or other Federal agencies. The districts are not authorized to levy any taxes or special assessments or to issue bonds.

Basic Considerations That Influenced the Drafting of the Act

The provisions of the act are intended to satisfy the following requirements, which are considered fundamental:

(1) A genuine attack on the erosion problem requires more than the construction of terraces and dams. Land-use practices and cropping programs must be adjusted in many cases.

(2) All the erodible lands must be brought under relatively uniform control. Arbitrary county and other boundary lines should be ignored, and programs formulated over watershed or other naturally bounded areas.

(3) This program can be made effective only if farmers can be induced to cooperate voluntarily. The act should, therefore, create machinery that the farmers can use when they are convinced that action is desirable. Some machinery, however, should be provided whereby a majority of the farmers may vote land-use regulations upon themselves and thereafter compel a recalcitrant minority to comply, where necessary for the public good.

(4) The farmers must be able to feel that the program is largely in their own hands. The provisions for petitions, referenda, and elections are designed to place the responsibility for initiating, formulating, and administering erosion-

control programs upon the farmers themselves, at the same time that expert guidance is made available.

(5) Because of the wide variance in conditions within a single State, land-use regulations must be formulated locally and must be flexible.

(6) The costs of the operations should not be thrown wholly upon the landowners, since the results of land treatment promote the general welfare.

Because of these considerations the standard act has been so drawn that it will enable farmers in any area voluntarily to organize themselves into a district to that they may apply on their lands the practices learned from State and Federal erosion-control demonstration projects. Complete power is reserved to the farmers to determine whether a district shall be organized, to elect a majority of the governing board, and to determine whether land-use regulations shall be adopted, and what such regulations shall provide.

Progress to Date

Forty-four State legislatures met in regular or special session during January to July 1937. These were the first State legislative sessions held since publication of the Department's recommendation for State legislation. In the following 23 States legislation was adopted at these sessions more or less along the lines of the standard act: Arkansas, Colorado, Florida, Georgia, Illinois, Indiana, Kansas, Maryland, Michigan, Minnesota, Montana, Nebraska, Nevada, New Jersey, New Mexico, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Carolina, South Dakota, Utah, and Wisconsin. In the following year, such legislation was adopted in California, Mississippi, and Virginia.

Statutes in this field were also adopted, in 1937, by the legislatures of Texas and Ohio. The statute in Ohio followed fairly closely the text of the standard act, while the Texas statute was a radical departure therefrom. These statutes, however, were vetoed by the Governors of the respective States. It is the writer's opinion that the veto of the Texas statute was fortunate in that it will clear the way for suitable State legislation. The veto of the Ohio statute is a serious set-back for the erosion-control program of the State.

The statute adopted in Montana is so sketchy, unclear, and unsatisfactory that it is doubtful that much, if any, progress can be made under the present law. Since most of the constitutional safeguards incorporated in the standard act were omitted in the Montana statute, the constitutionality of the act is more than doubtful. It may well be that the State committee in Montana can do no more than study conditions within the State preparatory to establishing districts after the present statute has been appropriately amended. Amendment is being sought by interested people in Montana.

The acts adopted in Minnesota, North Dakota, and Nebraska do not make adequate provision for enforcement of land-use regulations. In these States the laws omit entirely the standard act procedure whereby district supervisors are authorized, after securing a court order to such effect, to go upon the land of noncomplying owners, perform the necessary erosion-control work, and collect the costs from the owner. The California law makes no provision whatever for land-use regulations.

Arkansas, Illinois, Kansas, Minnesota, Nebraska, New Jersey, North Carolina, North Dakota, South Carolina, South Dakota, and Wisconsin have required more than a majority vote for approval of land-use regulations in the referendum. Most of these States require a two-thirds affirmative vote; Nebraska and New Jersey require a three-fourths vote; Minnesota requires an 85-percent vote, and Kansas a 90-percent vote. It is doubtful whether a provision requiring approval by 85 or 90 percent of the votes cast can be considered workable.

Colorado and California are the only States that have ignored the recommendation of the standard act on methods of financing operation of the districts. In lieu of appropriations out of the State treasury the Colorado and California laws authorize the districts to levy special assessments against the lands.

Without attempting a more detailed outline of the ways in which existing soil conservation district laws deviate from the standard act, it may be stated, in summary, that the statutes now in force should prove adequate for comprehensive erosion-control programs to be instituted in all but five or six of the States above discussed.

As this is written (June 1, 1938), 59 soil conservation districts have been organized, distributed over 16 States. It is still too early, however, to assess results. The work of the State committees and of the districts for the next year or two will necessarily consist in completing administrative organization, making the needed basic soil and other surveys, and informing the farmers of their rights and powers under the legislation. It will be clear that this is not the kind of program in which results appear overnight.

Relationship to Other Programs

As a final word, it should be noted that the soil conservation districts laws are of considerable value for more than erosion control alone. In particular, these laws are invaluable (1) for flood control, (2) to supplement retirement of submarginal lands from cultivation or other improper use, (3) for grazing regulation on private and public lands, and (4) to supplement rural zoning ordinances.

The Flood Control Act, approved by the President on June 22, 1936, recognizing that flood control requires supplementation of dams and other engineering structures on waterways with retardation and reduction of water run-off on the watersheds, has authorized cooperative work between the Federal Departments of War and Agriculture for operations on designated waterways and watersheds. The comprehensive work needed on the watersheds to retard run-off is in many cases the same work needed to control erosion. The programs of the soil conservation districts will, therefore, be at once erosion-control programs and flood-control programs.

The concept of "submarginal lands" includes lands that, if cultivated, make erosion practically uncontrollable. It was noted above that the soil conservation districts are authorized to purchase such tracts and keep them in grass or timber or otherwise retire them from cultivation.

Since overgrazing generally causes soil erosion, much of the needed grazing regulation may be accomplished under the programs and land-use regulations of the districts.

Finally, land-use regulations adopted by a soil conservation district may provide a valuable supplement to rural zoning ordinances. Many of the purposes of rural zoning—for example, the exclusion of settlers from submarginal areas—cannot be achieved under erosion-control regulations, so that rural zoning may remain necessary even where a soil conservation districts law has been adopted. The land-use regulations are themselves, however, a form of zoning, and supply needed controls within the zones established under a zoning ordinance.

RESETTLEMENT

In areas where there is little or no opportunity for nonagricultural enterprises and where the population is greater than the soil resources will support, the only alternatives are increasing poverty or migration of part of the population. The high birth rates in such areas intensify the problem. There are a number of these areas in the United States—areas of low agricultural productivity, heavy population, and high birth rates. They constitute the chief agricultural problem areas of the Nation and set the issue of resettlement. The issue is, Should there be a planned resettlement program?

Since it was unguided settlement, at times stimulated by governmental encouragement, that created these problem areas, it would seem not unwarranted for the Government to give serious consideration to means and methods of correcting the conditions that now prevail within them. And since, generation after generation, almost from the beginning of our national history, our people have demonstrated a willingness and desire to relocate in areas of apparently better economic opportunity, there is reason to believe that many of them who now find themselves living disadvantaged lives would welcome assistance and guidance in finding locations with relatively better opportunities. The problem of how to discover these opportunities and provide this guidance in relocation or resettlement is not easy of solution, but it should be clear that to find and apply the solution or solutions is a part of the task of conserving and developing the natural and human resources of the Nation.

Even if the assumption were valid, without modification, that persons are willing to migrate in the direction of economic opportunity, offering guidance to them and planning for their relocation or resettlement would not be easy. In a complex and rapidly changing society, knowledge concerning the stability of economic opportunities is not yet adequate to warrant surety in guidance. The localities and occupations that present the greatest opportunities today may not do so two or three decades hence, and those who move today may therefore find themselves confronted with the necessity of another move when they have passed the age of easy occupational mobility.

There is little doubt that a knowledge of or belief concerning better economic opportunities are major forces in stimulating migration. The relatively greater opportunity presented by cheap western lands was the chief stimulus to our westward expansion for a hundred years; the expansion of economic opportunities in industry, trade, transportation, finance, and the professions has been a major stimulus to the urbanward trend of our national population during the last 50 years; and the decrease in urban economic opportunities was un-

doubtedly the chief cause for slackened urbanward migration during the depression. But even among a people as mobile as ours, there are facts and conditions that cause thousands of persons to suffer considerable physical and economic inconvenience before they decide to change locations permanently, and resettlement is a type of migration different from that of following the seasonal demands for labor or the shifting about of young people during the period of life when they are seeking the best adjustments before settling down. By resettlement is meant the definite relocating of families with a view to at least relatively permanent residence in the new locations.

Furthermore, not all migration can be controlled, and present opportunities may be quickly taken up so that none are left for latecomers. This has happened a number of times and at a number of places in the past.

Such facts and conditions raise serious questions in planning for guided migration of "resettlers." Such questions are: (1) What localities or areas can best support a greater working population than they now have, and what localities or areas offer least economic support for the population now residing in them? (2) What are the best methods for helping persons and families to move from areas of low to areas of high economic opportunity, and shall they involve financial assistance, forced migration either directly or indirectly, or only education? (3) What persons, classes, or segments of the population now living in areas of low economic opportunity should be stimulated to relocate? Should they include only foot-loose persons, youths, young married persons, the old-age groups, those on relief, or portions of all of these groups?

These three major questions imply other issues, some of which need to be given serious consideration. One is the issue of whether people now living in poor-land areas and producing relatively little in the way of farm products for the market can be relocated in better farming areas without magnifying the already troublesome problem of surplus farm products. If they cannot, then the major objective of a resettlement program should be to assist them to locate in industrial or part-time farming areas.

Then there are a number of questions of a more complex nature that must be taken into consideration before a definitely planned resettlement program can be safely projected—questions such as: (1) How many or what percentage of persons now living in each agricultural problem area should migrate or relocate? (2) How great a change in habits and attitudes, methods of work, and standards of living can those to be located be expected to make? (3) Should such a program be part of a relief program, a public works program, or any other type of emergency program, or should it be cast on a long-time basis as a part of a national land-use and land-adjustment program?

There are no sure answers to some of these questions, but there is increasing evidence that the issues that give rise to the questions must be met. It is estimated, for instance, that there are from 650,000 to 1,000,000 farm families now living on and farming land that will not yield them even a minimum standard of living and that when they seek to wrest a living from such land, material damage is

done to the soil resources of the Nation. In these areas adequate educational, health, welfare, and transportation facilities and agencies can be supplied only by public aid of one kind or another. They have for some time been areas of poor housing and marked poverty, and in recent years have been receiving much public relief. It would appear, therefore, that it is the part of wisdom to provide such help and offer such governmental assistance as will aid the residents of these areas to become self-supporting. Furthermore, since it is quite evident that the resources of the areas cannot provide support, there would appear to be no feasible alternative to assisting some of these people to relocate. Thus it would appear that resettlement or relocation of a great many farm families should take place irrespective of whether they move to the city or to another agricultural area.

It is well known that wholesale and forced evacuation of population from agricultural problem areas would not be acceptable either to those now residing in the areas or to the general public, although there is considerable fiction in the notion that families now living in these areas do not desire to leave. Inquiries made in some of the areas concerning preferences of location reveal that great numbers of the people believe they would do better in other locations and express the desire to move. There is little doubt that many of them would eagerly accept guidance in resettling, if the adjustments incident to relocation and reorientation to work and general financial and social conditions are not too great. Nor is there much question that the financial aid required to assist a portion of them to relocate would be less than is now required to provide them with public services and relief.

In a program of resettlement, analysis of the amount of population which the resources of each specific area of location will support in agriculture and supplementary enterprises will be necessary to answer the question, How many of the present settlers should relocate? The ages, habits, training, and desires of the people will need to be known and considered. The areas for relocation will need to be studied carefully in the light of what is known about the habits of the resettlers and their best alternative opportunities in agriculture and nonagricultural occupations. It will also be necessary to discover or develop the best possible methods of educational guidance to assist them in making adjustments to their new locations and new occupations.

In planning for and providing assistance to farm families that need to move, too great a change in standards of living, customs, and traditions of those who have lived under physical and economic handicaps cannot be expected. Many of them will not adjust themselves easily to large-scale commercial farming and would probably make quicker and surer adjustments if they were guided into a self-sufficient type of farming, supplemented by income from other occupations. It is probably a mistake to expect them to assume a heavy burden of debt, however desirable it may be to improve their standards of living, by furnishing them all of the facilities in modern housing. They will make the adjustments more easily if the burden of debt is not too high and if the standards of living they are asked to assume are not too far above those to which they have been accustomed. It will be an exceptional family indeed that has lived in a very modest

house, has not been accustomed to real-estate debts, and has been unaccustomed to urban standards of living, that will not be swamped by a $10,000 farm enterprise, the total amount of which must be assumed as a debt.

During the depression and while an outstanding attempt was being made to provide relief by way of work for the unemployed, there was ample justification for making resettlement a part of emergency programs. The necessity for the relocation of hundreds of thousands of rural families, however, is a part of the necessary land-adjustment program of the Nation, which needs to be cast on a long-time basis and supplemented by plans for resettlement. A program of resettlement will be in keeping with the Nation-old habit of our people to migrate to areas of greatest opportunity and also with past governmental policy to assist citizens to find and improve these opportunities by moving to new localities whenever national welfare dictates.

RECLAMATION

The most common types of reclamation are irrigation of dry lands, and drainage and flood protection of wet lands. Although the Federal Government has participated extensively in the irrigation of arid lands, public drainage of wet land since the passage of the Swamp Land Acts has been primarily a responsibility of the separate States or of local communities.

The reclamation program can supplement various agricultural programs, particularly in the more arid parts of the country, by furnishing new family-sized farms under favorable agricultural conditions for distressed farmers. Productive agricultural lands are needed to supply farms for farmers whose less desirable land has been purchased by Federal agencies; for farmers who have been forced to abandon their lands in drought-stricken areas or in other areas which have proved unsuited to crop production; for young people reared on farms who wish to make farming their occupation; and as part-time farms for people who have small supplementary incomes. In many instances reclaimed lands can be used advantageously in supplying these demands for farms. In parts of the West additional supplies of forage are needed to supplement range feed, particularly during periods of unusually low precipitation. In some of these areas opportunities exist for isolated irrigation tracts too small to be well adapted to Federal projects. Federal assistance in the private development of the water supplies of these tracts for use in connection with the surrounding range would encourage a better use of range land.

The Federal land-utilization program includes withdrawing poor and submarginal lands from crop production and putting them to more extensive uses to which they are better suited. This program and the reclamation program are complementary, because one furnishes more productive farms for displaced farmers and the other tends to compensate for the addition of new lands to production by reducing the intensity of use of other lands.

A close relationship exists between the use of water and land in the arid and semiarid parts of the country. If natural resources are to be used most efficiently, coordination of the water-use and land-utilization programs is necessary. Each project should be compatible with the

general water-use plan for the drainage basin and the land-use plan for the area.

From time to time controversies over the use of water have arisen between individuals and even between communities and States. These disputes often cause long and extensive litigation, and the lack of prompt decisions retards development and the proper use of water for many years. Controversies between individuals and between communities within individual States are matters for State supervision. The development of standardized water codes to assist in obtaining uniformity is a field in which the Federal Government should furnish leadership. Furthermore, the adoption of policies that will expedite the settlement of controversies between States and promote harmony would be a desirable feature of our national reclamation policy.

In addition to assuming a stand on broader problems, a national reclamation policy should maintain a definite attitude toward the welfare of settlers on projects. Individual projects have resulted in varying degrees of success, but on some projects, including all types of reclamation enterprises, the settlers have found physical and financial conditions too adverse to allow successful farming. This situation has sometimes arisen where non-Federal projects were constructed as promotional schemes, where careful planning did not precede development, or where adequate safeguards for settlers were not adopted. On federally sponsored projects, however, settlers have reason to expect adequate safeguards for their protection.

Excessive cost of reclaimed land in some projects has been one of the more common causes of difficulties to settlers. High prices of reclaimed lands may be due to high prices of raw lands, to high cost of reclamation, or to a combination of the two. The value of raw land, based on its productive capacity before being reclaimed, is usually low and represents a relatively small part of the productive value of the reclaimed land. Raw lands susceptible to reclamation, however, are often held for speculation and eventually may be sold to prospective settlers at prices approaching the value of reclaimed land, although to this price must be added the cost of reclamation after the land is reclaimed.

The elimination of speculation in land in Federal reclamation projects has been attempted, and although it has not always been entirely successful in the past, it is becoming a definite part of our reclamation policy. Through an act of Congress a definite attempt is being made to eliminate speculation in the raw lands of the proposed Columbia Basin project. The aim of this measure is to control raw-land prices at least to the extent that profits from the sale of land above its appraised value will be turned over to the Federal Government to be applied against construction costs of the project. Some type of direct control of raw-land prices might logically be extended and made mandatory on all federally sponsored projects.

Another important factor in the cost to settlers of reclaimed land is the cost of engineering works and land preparation. Settlers of a project should not be furnished at Federal cost with an opportunity for exceptional profit, nor should they be penalized by excessive reclamation costs. A rational safeguard for protecting settlers is to

base the charges made to settlers for reclamation upon the capacity of the land to produce income under conditions of average management, rather than on the cost of the project, with the sponsoring agency assuming the resulting loss or retaining any profit on the development of the project. The adoption of this procedure as part of our reclamation policy would aid materially in establishing farmers on reclamation projects on a sound economic basis. To be effective, however, such a policy would have to be accompanied by restrictions on reselling land and water which might be similar to those mentioned for eliminating speculation in raw land.

During recent years several multipurpose water-utilization projects have been constructed in which hydroelectric power production, flood control, navigation, or recreational uses were combined with the storage of water for irrigation. For projects having more than one purpose, part of the cost should be assessed to each of the various uses based on the benefits received from that use. Such a policy is not new, but the determination of the amount to be allocated to each purpose has not always been worked out equitably. Measurable indirect benefits also should be charged to other interests receiving such benefits.

Owing to inadequate planning or to other reasons, lands poorly adapted to crop production have often been included in reclamation projects. Most of such inferior lands are never permanently settled; occasional attempts at farming almost invariably end in failure and ultimate abandonment. These difficulties could be largely eliminated if, through a joint investigation by the Bureau of Reclamation and the Department of Agriculture, the land is carefully classified on the basis of its capacity to produce income under conditions of average management, and if only land adapted to crop production is included in the project. When classes of land having materially different productive capacities are included, charges may vary with the quality of the land.

The total annual cost of operating a project must be prorated to the lands for which the project is operated. On partially settled projects, therefore, the annual cost of operation and maintenance tends to be higher than on projects that are completely settled. Slow settlement also lengthens the period of repayment of construction costs, and increases the cost to the sponsoring agency. Settlement often lags even on the better lands of projects. A plan for reasonably prompt settlement therefore would be of benefit to settlers by keeping annual charges from being increased and to the sponsoring agency by causing earlier repayment of construction charges. More rapid settlement might be facilitated by charging an agency whose primary purpose is the resettlement of farmers with this aspect of development, thereby relieving the construction agency of this responsibility.

To assure the maximum number of farms of sufficient size to furnish an adequate family living, new projects should be divided into family-sized farms. A farm of adequate size to supply a family living will vary with the crops and livestock produced. Such a policy should be accompanied by provision against farms being too small to return an adequate family living under the type of agriculture suited to the project.

A national reclamation policy should be concerned with projects in operation as well as with the construction of new projects. Many existing non-Federal reclamation projects are in need of some kind of assistance; in some the need is pressing. A system of Federal loans to irrigation enterprises has been in effect for several years, but adjustments accompanying such loans have not always been of a character to establish stable enterprises. Rehabilitation loans to reclamation enterprises predicated upon adequate land-use adjustments somewhat similar to those made to individual farmers would seem logical.

The rendering of assistance in solving these and similar problems might well be made a part of the national reclamation program. This type of aid, however, should be limited to projects which harmonize with land- and water-use plans for their respective drainage basins and which can be put on a sound basis by the adjustments. Distressed projects that are not in accord with these requisites might be aided by furnishing assistance in their liquidation and aiding the present occupants to find better opportunities elsewhere.

Some irrigation projects have been inadequately planned, and poor land is being irrigated with resulting distressed agricultural conditions, while within reach of the same water supply potentially productive lands are without water. In other instances more land is being irrigated than the limited water supply will satisfactorily serve. An outstanding opportunity exists to improve land use by rendering assistance in adjusting water supplies to the better irrigable lands. Such assistance should be extended to private as well as Federal projects.

Some of these suggested features are already in operation to a greater or less degree while others for various reasons have not been adopted.

CHANGES IN LANDLORD AND TENANT CONTRACTS

The present system of farm tenancy in the United States is seriously lacking in three respects which are of tremendous importance to concerted national efforts to conserve soil resources: (1) It does not provide an incentive for the tenant to maintain and to improve the farm he rents; (2) it actually forces the tenant to take a loss, in some instances, for making improvements; (3) there are many miscellaneous maladjustments in lease contracts which are often serious impediments to various programs or forces that tend to bring about soil conservation.

The two principal methods by which these shortcomings can be alleviated are by regulating landlord-tenant relationships, and by educating landlords, tenants, and the general public with respect to improved leasing practices. Both of these methods lie largely within the field of State action. Moreover, they are mutually related. Educational work is an aid to obtaining regulatory legislation, and, at the same time, regulation will stimulate educational processes.

Increasing the Security of the Tenant

The lack of an incentive on the part of the tenant to maintain and improve the soil arises principally from insecure tenure. Most leases are drawn for only 1 year at a time, and the tenant usually has

no assurance that the lease will be renewed for the next year. An individual tenant may live on the same farm for many years without knowing from one year to another that his lease will be renewed. Since he may have to move at the end of the year, he has little interest in maintaining the fertility of the soil. There are several ways to attack the problem of insecurity, but legislation, requiring, as it usually does, considerable public education, probably offers the best opportunity for action.

Many students of our tenancy system have recommended that State statutes should provide that all agricultural leases be written and should follow a form prescribed by law. Such statutes would obviate many of the minor misunderstandings between landlords and tenants from which a feeling of insecurity often arises, and in case of a major disagreement it would be easier for the courts, or for an arbitration board, to effect an equitable settlement. The responsibility of providing a written lease should be placed upon the landlord. Otherwise, if such a law were enacted and a landlord and tenant were to enter into an unwritten leasing agreement, the tenant might be considered a tenant at will or a trespasser. If the tenant were considered a tenant at will, his lease could be terminated at any time during the year by the landlord's giving a short notice, while if he were considered a trespasser, he could be put off the farm immediately.

The State law should prescribe the general form of the written lease to assure sufficient detail to be completely understandable. The prescribed form should include such matters as the date the lease was made, the names of the two parties, their signatures, the date the lease may be terminated, a detailed description of all the property rented, the amount of rent and when and where it is payable, the cropping system to be followed, and the number and kind of livestock to be kept. It should set forth also, definitely and concisely, all of the duties and responsibilities of the two parties with respect to the maintenance and management of the farm.

It has been suggested that State laws should require that agricultural leases be drawn for a period of 5 years or more. Another suggestion is that necessary adjustments would be made if the statutes would provide that all leases be automatically renewed unless there is 6 months' notice of termination from either party before the end of the lease. It does not appear, however, that the latter provision would solve the problem. It would not permit the tenant to plan long-time operations, and it would not prevent or even discourage termination of tenancies. The experience of several European countries indicates that long-term leases alone are not enough. Furthermore, many landlords and tenants in this country would look with disfavor upon such a requirement; they desire more freedom of action and they realize that many circumstances may arise to make it desirable that the lease be terminated before the end of a 5- or 7-year period.

It is probable that a provision embodying the good features of both of these suggestions would go a long way toward effecting a worthwhile solution. This provision should require that all agricultural leases be drawn for a minimum period of 5 years, terminable at the

end of any year by either party giving 6 months' notice, upon payment for the inconvenience or loss sustained by the other party resulting directly from unreasonable termination of the lease. However, termination of the lease should be allowed by the appropriate party at the end of any year without payment for inconvenience or loss under conditions similar to the following:

(1) The tenant's rent is delinquent.

(2) The tenant is not managing the farm properly.

(3) Either the tenant or the landlord is legally bankrupt or the property is foreclosed.

(4) The landlord or tenant has violated the terms of the lease, and the violation is not or cannot be remedied after notice.

(5) The landlord desires the farm for the purpose of farming it himself.

The lack of a quick and inexpensive mechanism for settling minor disputes and differences between landlord and tenant is a contributing factor to the insecure position of many tenants. Adjustments along these lines are badly needed. It appears impossible under present constitutional limitations to require that all differences arising out of agricultural tenancies be settled through arbitration, thereby providing the landlord and tenant with a swift and inexpensive method of settling disagreements. It is possible, however, for a State statute to require that all differences, except those involving the constitutionality of a statute and the interpretation of a statute or a contract, be settled before a single judge. Furthermore, it is possible to establish a small claims court to handle differences between landlords and tenants involving relatively small sums. In addition, it may be possible to require that if the landlord and tenant agreed to arbitration at the time the lease was made, this agreement would be irrevocable. Any of these adjustments would be worth while. If a small claims court or a system of arbitration were provided, it appears that the regulations pertaining to the court or the arbitration procedure should be included in the statute.

The security of the tenant can be enhanced somewhat by the enactment of State statutes which to a certain extent limit the landlord's lien for the collection of rent, particularly in cases of emergency such as a drought or rapidly falling agricultural prices. This adjustment is needed particularly in many sections of the Great Plains. In such instances, the landlord's lien may be limited to an amount not exceeding the customary share of the annual farm increases in crops and livestock products. In addition, the statute may well provide that the tenant cannot waive his legal exemption rights. Again, the landlord's lien may be either limited or declared entirely void if the annual rental is in excess of a maximum amount fixed by the State statute. This maximum rental might be made to vary according to prices, production conditions, or some other factor, or it might be a fixed share of the products. Of course, limiting the landlord's lien to an amount not to exceed customary share rentals and preventing the tenant from waiving his legal exemption rights would not be necessary if the amount of the cash rental were varied in an acceptable manner according to production conditions and prices, rather than fixed as a definite sum in advance.

Protecting the Tenant's Financial Interest in Improvements

Under our existing law, the tenant who improves the soil or fixtures on the farm is forced to assume an unreasonable financial risk. If a tenant makes improvements on the farm, such as building terraces or other erosion-control devices, liming the soil, growing legumes and winter cover crops, or building a pasture fence, he has no assurance that he will be allowed to remain on the farm to reap the benefits of the improvements or that he will be compensated for them when he moves. Indeed, his rent may be raised because of the improvements he himself has made. If tenants are to be effective soil conservers, our laws must be changed so that they will be protected against losses which they now incur when they expend labor and money in maintaining and in improving the farm, only to move before they get the benefit of the improvements. Few men will spend money to improve another's property without receiving some kind of remuneration.

One suggested method of protecting the tenant's financial interests in improvements is a statute which would give the tenant the right to remove, at the termination of the lease or within a reasonable time thereafter, all removable fixtures and improvements made by him. This provision would make it possible for the tenant to supply himself with fixtures and improvements necessary in the operation of the farm with the assurance that he could take them with him when he left the farm. It would grant the same rights to the agricultural tenant that are at present granted to businessmen and to nurserymen and gardeners renting land or buildings.

Many improvements are made, however, that are not physically and economically removable—for example, digging a well, terracing a field to prevent erosion, or improving a water hole. It may also be impossible or economically inadvisable for various reasons to remove such improvements as small buildings, temporary fences, feed racks, and corncribs.

State statutes, therefore, may well make it possible for the tenant to leave certain fixtures and improvements on the farm and claim compensation for them when the lease is terminated. They might be grouped into three major divisions, according to the freedom with which the tenant may effect them: (1) Those the tenant cannot make without the landlord's consent, including relatively permanent improvements such as large buildings, fences, works of irrigation or reclamation, and permanent pasture; (2) those the tenant can effect only when the landlord refuses or neglects to make them after receiving notice of the need for the improvement, including semipermanent improvements such as temporary buildings, home improvements, erosion-control devices, and works for the supplying of water; and (3) those the tenant can effect without the consent of or notice to the landlord, such as the provision of fertilizer, lime, or manure.

Dividing the improvements into these three major groups would distribute the control over the organization and management of the farm between the landlord and the tenant. The landlord would have the final decision as to the more important permanent or costly improvements in the first group. Both would have some control over

the making of the less permanent improvements in the second group; if the tenant made them, he should receive compensation at the termination of the lease, and if the landlord made them, he should be able to reimburse himself by charging a higher rental than that agreed upon in the original contract. The tenant would be free to effect the more temporary improvements in the third group, which require a relatively large outlay of labor as compared with capital.

In order to give the landlord and the tenant definite responsibilities toward conserving the soil, laws requiring the landlord to compensate the tenant for unexhausted improvements when the latter leaves should be supplemented by statutes—which would replace the present laws relating to waste—providing that the tenant shall compensate the landlord for deterioration to the farm arising from factors over which the tenant has control. Improvements made by the tenant should be allowed to offset damages for deterioration. Compensation for improvements and compensation for deterioration are closely related and must complement each other in order to be effective. The statute should define deterioration so as to include waste, injury, damage, dilapidation, and impairment of the property not involving ordinary wear and tear, and any change not due to natural forces.

When a State statute provides that the tenant should be compensated for unexhausted improvements and that the landlord should be compensated for avoidable deterioration, it should also set up a procedure for arriving at the amount of compensation payable. Experience in other countries has indicated that the value of the improvement to an incoming tenant is the best criterion to use in evaluating the amount of compensation payable to the tenant for improvements. It may also provide that the outgoing tenant can be compensated either by the landlord or by the incoming tenant. In case the incoming tenant compensates the outgoing tenant, the landlord should be required to assume the responsibility for seeing that the payment is made. This type of arrangement is probably appropriate in most cases of unexhausted improvements. The statute, however, should provide that the landlord and the incoming tenant may agree as to who is to compensate the outgoing tenant.

The amount of the damages payable to the landlord for deterioration should be based upon the decrease in the value of the property to an incoming tenant. In cases involving deterioration, compensation should be made directly to the landlord, and be payable at any time the deterioration occurs.

Regardless of how these payments are ultimately handled, the date or dates when the payments are to be made and the amount due at each date should be determined in such a manner that the person making the payments will not be financially embarrassed. For example, if the compensation for the unexhausted improvement involves a relatively large sum, the landlord or the incoming tenant should be permitted to reimburse the outgoing tenant by making annual payments over a short period of years. In this manner the landlord or the incoming tenant could pay for the improvement largely out of the increased earnings it made possible.

In order to facilitate the adjustment of compensation for improvements and for deterioration the statute should require that the written

lease contain a detailed description of the condition of the property at the beginning of the lease and that the tenant keep a record of all improvements made on the farm. Of course, the settlement with the outgoing tenant, which would include the record of improvements effected by him, would furnish an excellent record of the condition of the property at the beginning of the next lease, and should become a part of it. In this manner there would be a continuous record of the operation of the farm, and many of the difficulties likely to arise in determining the amount of compensation at the termination of the lease would be obviated.

Decreasing Maladjustments in Leasing Practices

Measures such as those here suggested for increasing the security of the tenant operator and for decreasing his financial risks in making improvements to the farm offer great opportunity to improve our tenancy system in such a manner that it will not be incompatible with national efforts to conserve the soil. There are, however, many other maladjustments in leasing terms and conditions within local areas and communities. Leasing practices now in vogue are largely the outgrowth of custom. They are static or very slow to change. Hence, changes in the type of farming often occur at a more rapid rate than changes in leasing practices. This often results in types of leases that are not adjusted to the existing types of farming in the local area. For example, crop-share leases still exist in many areas in the dairying and vegetable sections of the Middle Atlantic States that are very similar to those developed to meet leasing needs when these areas were important in wheat production. This inertia in adjusting the type of lease to the type of farming has caused wheat production to remain the basic crop on many farms where other enterprises would prove more profitable, and it has handicapped the tenants on other farms who are trying to follow new types of farming under old types of leases.

Moreover, the general westward migrations in this country have often resulted in leasing practices adapted to humid regions being imported into arid or semiarid regions. For instance, the type of leases used in the Great Plains are, to a large extent, importations from the humid areas of the Middle West, and the types of farming dictated by these leases are inimical to soil conservation and wise land use.

It is virtually impossible to classify the various types of maladjustments in farm leases into categories that permit of generalized suggestions for improvement. The problem is above all one which merits study, and which can best be attacked through educational programs. The needed adjustments of this general nature are usually not widespread and uniform enough to warrant State legislation. On the other hand, both State and Federal agencies may improve the leasing system through supplying individual landlords and tenants with ways and means of improving their leases. A certain amount of information is readily available upon which to build an educational program. A successful educational program, however, also depends largely upon additional research, which should be directed toward discovering and describing existing maladjustments in customary leases and proposing appropriate remedial measures within local areas and communities.

AMONG the knotty problems in agricultural finance, the reform of property taxes and the proper use of farm credit are two of the most difficult. Some broad principles at least may be suggested to bring both in line with the conditions that encourage rather than discourage soil conservation. In the case of mortgage financing, certain changes are needed to make mortgages more flexible and better suited to the nature of farming as a business, if both farm ownership and soil conservation are to be advanced. The authors of this article discuss how these things might be done.

The Remedies: Changes in Agricultural Finance

By Donald Jackson, R. Clifford Hall, Roy M. Green, *and* David L. Wickens [1]

PROPERTY-TAX REFORM

PROPERTY-TAX REFORM will be discussed here with reference only to such improvements in taxation as may tend to promote better use of land. It has been shown in an earlier article that land use may be adversely affected (1) by placing on real estate a burden of taxation so heavy as to increase the area of land subject to exploitative uses tending to destroy inherent productivity; (2) by failure to make allowance for deferment of income for the purpose of building up future productivity; and (3) by uncertainties and inequalities brought about through faulty administration of the property tax—especially through relative overassessment of low-priced land. Can these adverse effects be eliminated and a tax policy more favorable to sound land use be developed?

Lightening the Property-Tax Burden

The two fundamental methods of lightening the property-tax burden are reduction in revenue requirements and decrease in degree of reliance on the property tax.

Reduction in revenue requirements may come through reduction in governmental services or increase in governmental efficiency. Since reduction in local governmental services, except in unusual cases, is

[1] The section headed Property-Tax Reform is by Donald Jackson, Senior Agricultural Economist, Division of Agricultural Finance, Bureau of Agricultural Economics, and R. Clifford Hall, Director, Forest Taxation Inquiry, Forest Service. The section headed Farm Credit and Soil Conservation is by Roy M. Green, in charge, Division of Agricultural Finance, Bureau of Agricultural Economics, and the section headed Mortgage Financing as an Aid to Soil Conservation and Farm Ownership is by David L. Wickens, Finance and Credit Adviser, Rural Rehabilitation Division, Farm Security Administration.

neither acceptable to the public nor desirable from the social viewpoint, the most promising means of reducing revenue requirements is through increased governmental efficiency. Only those aspects of the problem which apply especially to rural regions will be touched upon here.

Increased governmental efficiency in many rural regions calls for reorganization of local government. As previously indicated, many existing forms of local government no longer fit modern conditions. Consolidation of governmental units and reallocation of governmental functions are among the measures which hold promise of increasing both the efficiency of governmental operation and the extent of genuine local self-government.

In very sparsely settled districts it would be desirable to dispense entirely with the usual type of local government. This has been done in a section of about 10 million acres in northern Maine. Property in that section enjoys moderate taxes, paid directly to the State. The few residents get the benefit of all essential governmental services, provided in large part directly through State agencies. The remainder of the State does not have to help support the sparsely settled sections in Maine as frequently happens in other States, since the taxes paid in this unorganized territory exceed the cost of governmental services.

Public control of land use through zoning ordinances also would tend to lower the cost of local government in rural regions. Such control would concentrate settlement where successful farming is possible and allow the closing of schools and roads in many districts where they are now provided at excessive cost. Zoning is obviously a more direct control of land use than is taxation, but its economic soundness and political feasibility depend partly upon attendant adjustments in forms of taxation and in allocation of governmental functions.

Many rural districts are now overburdened with taxes because public functions of general concern, such as education, rest too heavily on local support. In any reorganization such districts should be aided by State assumption of at least some part of these functions. Already the State of North Carolina has gone so far in this direction as to take over the financing both of the public schools for the constitutional minimum term and of the entire road system, and several other States have taken significant steps in the same direction. A second way of relieving this situation is to extend the system, already established in many States, of State aids to local districts for schools and other purposes. A third avenue of relief is through State-collected, locally shared taxes. Such aids and shared taxes must be carefully safeguarded, however, lest they promote extravagance and maintain uneconomic units of government.

In addition to gains through reorganization, more efficient and economical administration of rural local government can be obtained by greater use of trained administrators, better financial practices, and more State supervision. Responsibility can be promoted by the short ballot, the budget, full publicity, and other means of citizen control. Losses in public revenue can be avoided by good administration of the tax system itself, a subject to be discussed later.

The matter is of special interest to land use because of the relatively heavy burden of local government cost in "marginal" communities. Such communities need assistance either to survive on a sound social basis or to vacate the areas. To try to maintain uneconomic and partially vacated areas is to squander much of both the land and the human resources involved.

Not only may revenue requirements be reduced through reorganization of local governments and more efficient and economical administration, but also the property-tax burden may be lightened by greater reliance on other forms of taxation.

Ultimately all taxes must be paid out of income. In many cases, however, individuals must for a time pay their taxes from other than current income. But neither on the principle of ability to pay nor on that of benefit received from government is current income, by itself, an adequate base for the entire tax levy. Nevertheless, an income tax is the one measure in a balanced tax system which tends to mitigate the hardships of the property tax during periods when there is little or no income from certain classes of property. Greater reliance upon the net income tax is one means, wholly favorable from the land-use viewpoint, of redistributing the tax load.

Another means of redistributing the tax load so as to place less reliance on the property tax is the use of the general sales tax. The effect of such a tax is regressive; that is, the lower the income the higher the portion of income taken by this tax. Consequently the use of the general sales tax as a means of tax relief offers limited benefit to the small landowner or small farmer, since the reduction in property tax would tend to be offset through the payment of the sales tax. On account of this regressive character, the general sales tax is widely condemned as socially undesirable except perhaps in connection with a personal income tax at sharply progressive rates made effective by shutting off the supply of tax-exempt securities and other means of avoidance. Selective sales taxes may be less objectionable socially, but relatively few are important as revenue producers.

It has been suggested that a turn-over, or sales tax, or a capital-gains tax, on real-estate transactions might serve to reduce the property tax and to operate as a deterrent to land speculation. The frequent sale of a property often leads to its abuse and rapid deterioration. If stability in ownership would be promoted by such taxes, their effect on land use would be to that extent favorable. A capital-gains tax would perhaps involve fewer injustices than a turn-over tax.

Either the turn-over or capital-gains tax, in order to have the greatest effect in stabilizing land tenure, would require special application to real estate and classification of rates by length of ownership. The higher rates should apply to quick turn-overs which are composed most largely of speculative transfers. Although both turn-over taxes and capital-gains taxes are now components of the Federal tax system, there are serious obstacles to their employment to improve land use. There would probably be constitutional objections in many States to applying a special capital-gains tax to real estate, especially to rural real estate alone. There probably would be even more strenuous objections to a set of rates decreasing with length of ownership or tenure. Nevertheless, taxation of this type designed to favor im-

proved land use appears worthy of further study. Normally a rapid turn-over of rural lands, either as to ownership or as to tenure, is an activity harmful to society. On the other hand, any measures to stabilize ownership or tenure should make certain not to hinder desirable readjustments in land ownership, such, for example, as consolidation of small forest properties where necessary to establish economic units.

Another suggestion for reducing the total burden of the property tax is to establish by law or constitutional amendment a maximum property-tax rate. Experience with such limitations is that they have either been too high to be effective or have been followed by embarrassing fiscal complications. They have often been nullified by changes in assessment. In some cases they have led to financing current needs from borrowings, thus piling up the local public debt. Expert opinion is divided as to whether limitations of this kind can be made an effective restraint on the property-tax burden. If such restraint were effective and unattended by these complications, over-all rate limitations would favor sound land use by keeping the tax burden down and giving assurance of its stability.

A tax modification now in operation in 10 States, awaiting enabling acts in 3 other States, and widely considered elsewhere, is homestead exemption. This is a form of limited property-tax exemption in favor of owner occupants, and its purpose is to increase this class of ownership. Benefit to rural land use resulting from increase in occupant ownership must depend upon any differential incentive of owner occupants to follow improvement and conservation practices. Both form and extent of exemption vary considerably from State to State. If the maximum exemption is made substantial there appears little doubt that the declared objective can to a considerable degree be attained.

There are, however, questions as to the social value of the homestead-exemption plan. For one thing, a revenue problem is created. Since exemptions from the property tax are allowed, equivalent revenue must be raised from other sources, either from other property through increased rates, or from other types of tax levies. This does not condemn the measure more than it does any tax decrease which requires offsetting increases elsewhere in the tax system, but it does raise serious questions as to the ultimate economic or social effects.

Homestead exemption generally will benefit present owner-occupants. The extent and distribution of the benefit will depend, of course, upon the way in which the decrease in revenue, due to exemption, is offset—either by redistribution of the property tax or by partial substitution of other taxes. Homestead exemption will also offer a potential benefit to other present and prospective owners, the apportionment of the benefit between buyers and sellers of affected properties being determined by competition in the land market. There is also perhaps a question whether new owners would obtain real control or only nominal ownership. At least it can be expected that in many cases increased debt charges, resulting from the reflection of lower taxes in higher values, will substantially offset current tax exemptions. On the other hand, some incentive would be given to the subdivision of large and valuable properties.

Special Adjustments for Deferred-Income Uses

The taxing of deferred-yield property, that is, property the future productivity of which is being built up at the expense of current income, presents special problems. As pointed out in an earlier section, the question of equity between different owners is not involved, for if deferred-yield properties are properly assessed, giving full effect to the prospective burden of carrying charges, and if the tax rate is uniform, all property owners are treated equitably.

Even with proper assessment, however, the property tax definitely discourages land uses involving deferred yield. It may appear desirable to encourage certain types of land use by special aids, and this may be done for deferred-income properties by relieving them of the carrying charge for taxes or by offsetting this charge in some manner. Thus taxes on orchards and vineyards might be deferred or reduced until bearing age is reached. The same reasoning applies to cases of crop failure, but, of course, the tax-carrying charge in such cases is less important where the deferment is only for 1 or 2 years. In the case of crop failure, crop insurance would be a more feasible means of protecting desirable use of land than would tax adjustment; it would give greater continuity in the flow of local governmental revenue and be simpler to administer.

If a long period of income deferment is involved, the problem becomes a serious one from the land-use viewpoint as indicated in an earlier section. Forests, in their present depleted condition, are an extreme and important example. There is much sentiment for tax concessions to help forest properties to continue production and to become established on a sustained-yield basis with regular income realized annually or at short intervals. Whether the special need will be restricted to a developmental period while the growing stock necessary to a regular annual income is being established, or whether it will persist indefinitely owing to obstacles to sustained-yield management, aside from taxation, is here a question of secondary concern. In either case, tax concessions which encourage continuity of the forest use and the building up of forest growing stocks will result in increasing physical productivity, which in turn will bring about greater taxpaying ability in forest properties.

Special taxation treatment of forests is looked upon by many persons as a subsidy, but such treatment is a subsidy only in the sense that any classified property tax is a subsidy to the classes to which the lower rates apply. Such treatment would give an advantage to the present forest owners affected by increasing the value of the properties, and might be regarded as inequitable from the standpoint of other property owners. Purchasers thereafter would reap no such advantage, because there would occur a recapitalization of the tax savings expected. The real foundation for such special treatment, however, is the desirability of eliminating taxation obstacles to the development of continuously productive forests which will serve the public interest in many ways, including eventual increase in the property-tax base. Means of accomplishing this objective through special forest-tax plans will now be considered.

A direct way of adjusting the tax burden on forest property to deferment of income would be to exempt such property from the prop-

erty tax and apply an income tax instead. Since it is impossible to determine net income from the irregular forests characteristic of this country by any practical method, it has been proposed that there be applied instead what is known as a yield tax—a tax on gross income measured by the stumpage value of the felled timber. This remedy has been tried in a limited way in a large number of States and has been found to involve disadvantages which have prevented its effective operation on a broad scale. A preferable method would be to retain the property tax but eliminate its deterrent effect on deferred-yield forestry. This could be done by so modifying the property tax that it would impose a tax burden roughly equal to that of a tax on income or net yield at a rate equivalent to a property-tax rate.

An income-tax rate is here considered equivalent to a property-tax rate when the two rates, if applied to a property yielding an annual income after taxes equal to the interest on the capital, would give the same amount of tax. For example, a capital of $100 yielding an annual income of $4, before deduction of the tax, would be taxed $1 (1 percent of $100) under a 1-percent property-tax rate and the same amount (25 percent of $4) under a 25-percent income-tax rate. In this case, the tax-free interest would be $3. Thus, with a tax-free interest rate of 3 percent, an income-tax rate of 25 percent is considered equivalent to a property-tax rate of 1 percent. When applied to a deferred-yield property, however, an unmodified property tax of 1 percent will constitute a heavier burden (in the sense that it will tend to bring more land into annual-income use) than an income tax of 25 percent, because the property tax must be paid in advance of income realization. The income and property tax will be equal only when the income is received annually.

It is proposed that the property tax be modified in one of three ways in order that its burden may thus approximate that of a net income tax at an equivalent rate. The first is to reduce the current property-tax base in the case of the deferred-yield forest property by an amount proportioned to the extent of income deferment in each individual case. The second is to defer the payment by the forest owner of property taxes until income is received. The third is to give preferential assessment to timber in accordance with the degree of income deferment which may be considered typical or average for the State. The details of these three plans are described elsewhere and need not be given here.[2]

Improvement in Property-Tax Administration

One of the aspects of rural tax reform of greatest general importance is improvement in the operation of the property tax, especially in the process of assessment. Thoroughgoing changes in assessment organization and personnel are needed. Assessment should be centralized under control of jurisdictions large enough to maintain an efficient organization of full-time, well-paid, expert assessors appointed on a merit basis. In general, assessment by the State would appear to be the ideal procedure and, next best, centralization by groups of

[2] For full details refer to Forest Taxation in the United States (*105, pp. 576-608*).[3] For a brief treatment see The Forest Tax Problem and its Solution Summarized (*138, pp. 12-17*).

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

counties or towns. Where neither one of these measures can be obtained, local assessment may be improved by an increased degree of State control and assistance. Along with organization and personnel improvements, the most approved aids for arriving at sound assessment should be introduced. These include maps, surveys, and records of sales. The goal obviously should be a reasonably correct assessment of all property.

In some States a step has been made toward assessing individual properties by types of land, the recognized types being based chiefly on land use. This method facilitates giving full effect to the economic limitations on various types of land, such as woodland; land requiring erosion control, permanent sod, or forest planting; or land completely withdrawn from production. Without any attempt to change the fundamental concept of value for tax purposes, such an assessment would tend to be more equitable to properties containing land of low productivity, and would tend to rest more than does the usual present method upon the enduring qualities of the site. It would directly influence and tend to stabilize the use of many low-value lands by requiring that classification for assessment purposes correspond with the most intensive actual use.

The procedure of tax collection should be made as simple, regular, and certain as possible. Both excessive rigidity and extreme leniency should be avoided. The period allowed for redemption of tax-forfeited land should not be extended unduly, so that land which cannot be restored to the tax roll by sale may be definitely transferred to public ownership and placed under public administration. The details of procedure in tax collection have been given careful study, and information as to methods which have proved effective is readily available.

The Three Principal Reforms

In brief, the measures of property-tax reform of most importance from the land-use viewpoint are: (1) Lightening of the total burden of the property tax through increased efficiency of local government and greater reliance on other forms of taxation; (2) concessions from the uniform application of the property tax in favor of certain desirable types of land use where income deferment would otherwise impose a tax handicap, the most important case being that of forestry; and (3) improved property-tax administration, especially more equitable rural assessments, as a means of eliminating overtaxation of low priced lands and of promoting that confidence in the reliable operation of the tax system which is essential to long-range land-use planning. Clearly, taxation is only one of many problems involved in bringing about better land use. Nevertheless, its solution would be a real contribution to progress in this field.

FARM CREDIT AND SOIL CONSERVATION

Credit has a definite place in soil maintenance. It can properly be used when there is every reason to believe that the abnormally low margin between farm expenses and farm income is temporary. Such credit should be repaid as soon as possible after normal operating margin returns. Where conditions are such that the margin between

expenses and income is constantly small, credit in the long run will be of little help. It will merely add to the accumulated debt burden of the operator.

Soil maintenance is a secondary lien on farm income. Farm soils, as well as farm buildings and equipment, are permitted to depreciate most rapidly when it is most difficult to make farm income cover other farm expenses. Depreciation is normally an operating expense to be paid for out of income. In the case of the fertility of farm soils, however, if income is too small to permit of maintenance, the soil can be exploited for a time without any current expense for replacement. Farming then becomes similar to mining, in that its profitableness depends upon the time it takes to deplete its natural resources. Because soil maintenance is an expense that can thus be deferred, it is one of the first to be currently eliminated whenever other expenses begin to absorb farm income.

Soil restoration in cases of severe depletion, where such measures as reforestation are needed, seems in the main to be beyond the capacity of the individual operator. To him the cost stands as a long-accumulated debt that has been steadily compounding. With other expenses as prior liens against his income, this past accumulation has frequently gotten beyond his ability to pay.

Easy Credit May Become Heavy Debt

Easy credit may be easy in two entirely different senses. It may be (1) easy to get, (2) easy to bear. If credit is too easy to get it may not be so easy in the second respect.

Generally credit is extended, and debts are incurred, in terms of dollars. The extent to which a certain commodity price can be depended upon for debt-paying purposes may be illustrated by 60 years' experience with average annual wheat prices. In table 1 are shown the number of years by 5-year periods that average annual wheat prices were near to or below $1 a bushel and the number of years they were distinctly above $1 a bushel.[4] This is shown for two entirely different 30-year periods--1866–95, in which the general trend in prices was downward, and 1896–1929 (excluding 1917–20) in which the general trend was upward part of the time.

Yet 8 to 10 years of prices above $1 a bushel appear to be a warning signal. In one period wheat prices were above $1 a bushel for 12 years and in the other period for 13 years. Such figures are called to attention merely as an example of the possibility of establishing at least a rough criterion whereby farmer borrowing may be based to a greater extent upon estimated earning power, though major reliance continues to be on tangible assets.

If credit extended in the present becomes a heavy expense burden in the future it only puts off the time when soil mining must start and thus eventually works against soil conservation. On the other hand, credit properly used can be helpful in promoting soil conservation.

[4] Chicago wheat prices, Yearbook of Agriculture 1935 (*430, pp. 349–350*). In this classification, annual average wheat prices were grouped according to the nearest 10-cent interval, as for instance $1 wheat for the purpose here used means either 96-, 97-, 98-, or 99-cent, $1, $1.01, $1.02, $1.03, $1.04, $1.05 wheat. Likewise, 90-cent wheat means wheat at 86 cents, 87, 88, 89, 90, 91, 92, 93, 94, or 95 cents, and so on for the other ranges.

Table 1.—*Number of years by 5-year periods that average annual wheat price was at or below $1 a bushel and above $1 a bushel*

5-year periods	Years in which wheat price was—		5-year periods	Years in which wheat price was—		5-year periods	Years in which wheat price was—	
	At or below $1 a bushel	Above $1 a bushel		At or below $1 a bushel	Above $1 a bushel		At or below $1 a bushel	Above $1 a bushel
	Number	*Number*		*Number*	*Number*		*Number*	*Number*
1866–70	1	4	1886–90	5	0	1911–15	3	2
1871–75	1	4	1891–95	5	0	1906–10	4	1
1876–80	2	3	1925–29	0	5	1901–5	5	0
1881–85	4	1	1916–25 [1]	0	5	1896–1900	5	0

[1] 1917–20, inclusive, wheat-price-control period, omitted

Seed loans, feed loans, drought loans, and various emergency loans, as well as mortgage credit, can maintain their purely credit aspects only if in total they are not in excess of the earning capacity of the land. Credit extended beyond the earning capacity of farm land creates a debt structure for individual farmers that invites one or more of several contingencies:

(1) Credit beyond earning power rests partly on what the tangible assets pledged will sell for on the market over and above their value based on earning power. To collect such credits in full means, in adverse periods, foreclosure and the placing of the tangible assets on the block. Such credit extension may become merely one means of acquiring property by lenders.

(2) Credit beyond earning power may require a lowering of interest charges to avoid wholesale foreclosures. As an example, if an individual farmer has an indebtedness exactly four times the average annual gross farm income and bearing annual interest payments of 6 percent, such annual interest payments would require 24 percent of the gross farm income, meaning that all other expenses, including living, could not consume more than 76 percent of gross income. If the annual interest rate is reduced to 4 percent, only 16 percent of the gross farm income is required for debt service. There is, therefore, necessity for a reasonable relationship between farm indebtedness and average farm earnings.

(3) Credit beyond earning power may mean ultimate scaling down or writing off of part of the debt. This part of credit then assumes the aspect of relief, bounty, grant, or subsidy, though for years it bore the name of credit.

Credit beyond earning power of farm land, therefore, contributes in the long run to a decrease in ownership by operating farmers or to a subsidized use of land that is a strong influence toward perpetuating misuse of land from the standpoint of its conservation.

Suggested Reforms in Extension and Use of Farm Credit

From the standpoint of the extension and use of credit that will facilitate soil conservation rather than encourage mining of the soil, several modifications in credit practices may be suggested.

(1) In the extension and use of credit, more emphasis should be put upon estimated earning capacity of the property loaned on and less on the speculative market value of the tangible assets given as security.

(2) Basic prices above which lenders will not go in determining estimated earning power of tangible assets should be established, as

well as basic prices below which they will not go in periods of price decline.

(3) More attention should be given to regulating the maturity and the terms of loans as prices approach the maximum and minimum base prices established for determining estimated earning power of tangible assets.

(4) Relief, bounty, grant, or subsidy in necessary and meritorious cases should be recognized as such and not be confounded with credit in such a way as to set up a debt out of all proportion to estimated earning power.

Credit that is easy to get but only easy enough so that it is easy to bear will be an inducement to soil conservation.

A proper understanding of the economic value of credit, judgment and prudence in its use, are, therefore, at the very foundation of any successful credit system. Strained beyond its proper though restricted purpose, it may become, instead of a help, a burden or even a danger (*130*).

MORTGAGE FINANCING AS AN AID TO SOIL CONSERVATION AND FARM OWNERSHIP

It is not necessary that farm-mortgage financing should be so arranged as to obstruct soil conservation or to create added difficulties for the maintenance of farm ownership. Insofar as the factors are within control of the borrower and lender some improvements over past practice may be arranged when the mortgage is given. The farm mortgage is a contract, and its provisions can be made to include whatever arrangements are best calculated to establish and preserve the productivity of the farm and to afford greatest financial convenience to the borrower. These provisions of the loan contract may be directed toward the correction of the faults disclosed by past experience and may extend to as many features as it may be desirable to make definite provision for.

Since the loan is always based on the farm, the care and management of the farm is of first importance. The farmer must not only know what is the best practice, but he must carry it out effectively. Both the borrower and the lender have an interest in insisting upon effective management and far-sighted use of the soil, the former because his livelihood depends on maintaining the value of the property while he is operating it and after he has paid for it, the latter because the mortgage he holds can have no more value than the farm on which it is made. If good management can be assured, certain features of the farm financing may be arranged to avoid other dangers, and the loan contract may be made a further aid to conservation.

This identity of interest of buyer and seller suggests that both parties should be willing to include in the terms of the mortgage contract certain provisions giving definite assurance that all necessary measures will be taken to conserve the fertility of the soil. Such provisions may wisely go beyond those general statements occasionally made (if not read) in present-day mortgages providing that the farm will be well tilled. They may desirably include specific provision for kinds of crops and their rotation, the use of livestock on the farm, and possibly other practices. Such a contract gives the buyer an opportunity to assure the creditor of his intention and capacity to

care for the property according to the best practices. Where possible some form of inspection or cooperative supervision may be arranged between the owner and the holder of the mortgage or his agent for carrying out soil-use practices and other features of farm management that permanently affect the value of the farm. In return for such specific assurances to the creditor regarding desirable provisions, the borrower may bargain for putting certain other provisions in the contract that will be of great assistance in enabling him to carry the debt successfully. Conditions of purchase and of financing designed to avoid undue financial pressure on the new owner in times of emergency and to forestall some of the bad soil practices that follow such pressure are illustrative of these gains for the borrower.

Assurance as to the qualifications of the borrower often merits specific provision. If a prospective owner has not had previous farming experience, the first question is whether he wishes to own a farm and to undergo the hardships that often attend saving to pay for it, or whether he prefers to rent. Many who have a vague desire to have a farm of their own but who have not undertaken a systematic accumulation of savings from farm earnings are not prepared for the stern realities that farm purchase usually involves. It is generally desirable for the buyer, therefore, to undertake a preliminary period of tenancy to provide opportunity for him to discover whether he has sufficient interest in farm ownership to undertake the responsibility. This lease arrangement may be made a part of a conditional sale and mortgage contract which goes into effect after the trial lease period.

Furthermore, it is desirable to require that the purchaser possess enough savings to make at least a small initial down payment, or in the absence of such payment that the borrower operate under a carefully developed farm plan with competent supervision. If the prospective buyer accumulates these savings as a result of actual farming operations, he is given an opportunity to learn more clearly the problems and difficulties that are likely to confront him during the time required to pay the full price of the farm. After a trial he may conclude that he prefers to rent, particularly if it is possible to obtain many of the advantages of ownership through an improved leasing arrangement. This preliminary period of accumulating the first amounts necessary for financing should be used by the prospective buyer for distinguishing carefully between the advantages of stable tenure, long-term farming plans, and continuous residence in a community that are possible under improved long-term leases, and those features that are distinctive to ownership itself, as for example the personal accumulation and possession of an amount of capital equal to the value of the farm.

In considering the essentials for a successful financing arrangement for purchasing a farm, there is no substitute for the desire to own a farm or the will to operate it well. When these are lacking or when they disappear, efforts to establish the farmer on a farm are useless and without purpose; both the use of credit and its terms become of no consequence.

Given a desire to buy a farm and the willingness to undertake the work involved, the first danger to be avoided is that of paying too high a price for the land, that is, a larger amount than long-term farm

prices or farm income will support. This danger is especially acute in periods of land booms. For the most successful financing, it is essential to keep the amount of the loan within the amount of the long-time value of the property, since the value of the farm is limited by its present and future income and this income is the means upon which the farmer must rely in carrying the debt.

Other features of farm financing that should be improved if soil conservation is to be assured and farms are to be held by their owners are associated with the principal terms of the loan. These include the interest rate, the length of the term for which the loan is to be in effect, the methods for repayment of the principal, the frequency of payment, and the conditions necessary to keep the loan in good standing.

The first essential in the contract terms is that the average total annual payment required to carry the mortgage should not exceed the average share of the farm income that can be devoted to payment of interest and principal and still leave enough for farm operating expenses and an adequate amount for family living. Occasional years may be expected when it is necessary to curtail expenses severely and even reduce inventory to meet required payments, particularly if a large proportion of credit is employed in buying the farm.

Given a farm that is fairly valued and an amount of debt that does not exceed this value, the principal provisions for which more constructive mortgage contracts should aim center about the arrangements for carrying the loan in good standing and repaying the debt. The farmer who aspires to own his farm free of encumbrance will find his chances of ownership improved by having some form of amortization that gradually reduces the debt. Under this plan the payment is a combination of the rate of interest plus payments on principal. Amortization payments on principal seldom exceed 1 or 2 percent of the debt per year. Private loans occasionally require larger amounts. If amounts are larger than the practicable rate of saving, difficulty results.

For most mortgages the charge for interest accounts for the largest part of the annual carrying cost. Though the rate of interest usually varies with differences in risk throughout the country, the general level has declined in recent years. The average rate now in effect is probably 1 percent lower than the average of about 6 percent that prevailed during the years 1910–30. The contract rate on loans from the Federal land banks and some important private sources of mortgage credit is 2 percent lower, or 4 percent per annum. The Farm Security Administration rate for tenant purchase loans is 3 percent. A loan of $4,000 that formerly bore a rate of 6 percent had an annual interest charge of $240. A loan of the same amount at 5 percent would require $200, and at 4 percent $160. A lowering of the interest rate by 1, 2, or 3 percent, therefore, means reductions of 16⅔, 33⅓, and 50 percent, respectively, of the total interest charge. These reductions represent substantial savings that are of assistance to the farmer who is already in debt or who is about to buy a farm.

The advantage gained for the borrower by these savings may be largely lost, however, if the lower rate is used to capitalize the same income into higher land value. The buyer should be cautious about

capitalizing the value of his farm at a rate that is temporarily low or that may not be sustained. Overvaluation, whether based on large income falsely assumed to continue or on a low interest rate assumed to continue, is probably the greatest obstacle to good farm practice and to farm ownership. Insofar as the general interest rate is involved, the borrower and lender may have no control over it, since the level of money rates will be influenced by general economic conditions and public policy.

Apart from the interest rate, the timing of payments offers the greatest means of accommodating financing terms to good care of the soil and its acquisition. Typically, a long period is required to make any substantial reduction in the principal of the mortgage. Amortization of loans, even at the usual amortization rate of 1 percent a year, is not sufficient, however, to avoid the danger of delinquency and default. In 1932, 52 percent of long-term amortized loans were delinquent, or about the same proportion as for short-term straight loans. Delinquency is closely related to the total annual amount payable for debt service. The requirement of a fixed amount of payment established in the mortgage contract, contrasted with the fluctuating size of the farmer's annual cash returns, has presented one of the most difficult situations that arise in connection with farm-mortgage financing. It has contributed liberally to the depletion of the soil of many farms and has been a prolific cause of defaulted loans and increased tenancy in the United States.

Traditional financing has established a system of uniform payments for keeping loans in good standing. They are fixed in advance, do not vary from year to year, and bear no necessary relation to farm income. They include payment of interest at regular intervals and in some cases amortization payments. This is a rule-of-thumb method that prevails widely in the commercial world. Experience has shown that it is ill-adapted to the conditions generally found in agriculture, where income is highly variable because it is reduced in times of bad crops or low prices as well as in times of general economic depression.

Since variations in farm yields and cash returns available to the farmer and his family cannot be eliminated, it is desirable to make farm-loan contracts that will recognize these fluctuations. The experience of the last three-quarters of a century offers convincing evidence that agricultural income may be expected to continue to vary in the future. There appears to be no good reason why annual payments of interest and principal on farm mortgages varying with prices and yields for major crops cannot be arranged. The process of acquiring ownership of a farm clear of debt is a long one. It is highly desirable, therefore, that credit arrangements should be framed from a long-run viewpoint. It should be practicable to make a loan payable on or before the expiration of a designated long term and to vary the amount of annual payments with the principal changes in the farm income. The interest rate would be fixed, but the amount payable in a specific year would vary. Likewise the number of years required to pay the loan would vary within the term limit.

Congress has recognized the defects of the prevailing system of farm mortgage finance in the Bankhead-Jones Act. Under provisions

of this act loans made to tenants for the purchase of farms may provide for variable payments to conform with the farm income and to carry favorable interest rates and long terms.

Necessary safeguards can be inserted in the contract to avoid overextension of debt to an amount in excess of the value of the security, but the flexibility permitted within these limits would save a great deal of the distress now experienced by farm families in periods of poor farm returns. Safeguards can provide for a maximum limitation on the amount of the loan and minimum requirements for the amount to be paid in any one year. This will meet the creditor's desire to have the total loan repaid with interest within a specified term of years. At the same time the borrower may have the benefit of credit accommodation in purchasing a farm with a flexible requirement whereby annual payments vary with his farm income. Such a credit arrangement is only an adaptation of the plan of buying or renting on a crop-share plan, a method familiar to most farmers. Crop failures or low prices will then not interfere with soil practices nor with the farmer's ambition to acquire a farm. Such a mortgage contract, providing for variable payments and for soil conservation and carrying a moderate rate of interest and amortization, will make farm mortgage financing an aid to good farming and farm ownership.

ON THE BASIS *of recent experience, what conclusions may be drawn as to the usefulness of conditional grants to farmers in return for soil conservation practices and crop adjustments? What about the effectiveness of assistance not in the form of direct grants but in the form of labor, materials, equipment, and technical advice? What are the drawbacks of these methods, and what precautions should be observed in using them? The authors of this article have tried to answer these questions realistically but briefly.*

The Remedies: Direct Aids to Farmers

By O. V. Wells, J. P. Cavin, *and* D. S. Myer [1]

CONDITIONAL GRANTS

CONDITIONAL grants—that is, grants by the Government to farmers who carry out certain practices or meet such other conditions as may be specified—seem to offer considerable promise as a means of inducing conservation on privately owned land. Although a wide variety of grants-in-aid have been used by the Government in order to encourage State cooperation in such lines of work as agricultural and vocational education, agricultural research and extension, child welfare and public health services, and highway construction, such grants have been used as a means of directly inducing action on the part of farmers only since the enactment of the Soil Conservation and Domestic Allotment Act early in 1936.[2] As a result, it is desirable to give some consideration to the arguments upon which this approach is based before an attempt is made to describe its operation and to outline some of the problems involved.

Prior to 1933, the conservation movement in the United States was directed chiefly toward the protection of natural resources still under Government control, since it was assumed that individual interest would prompt the conservation of resources on privately owned land. Actually, the assumption that the short-time interest of the individual and the long-time interest of the individual or of the Nation are the same is often unfounded. The average farmer is usually interested in maintaining his immediate income at as high a level as possible in order to meet minimum living and operating costs and, if possible, to

[1] The section headed Conditional Grants is by O. V. Wells, Principal Agricultural Economist, and J. P. Cavin, Agricultural Economist, Production Planning Section, Agricultural Adjustment Administration. The section headed Technical and Other Services is by D. S. Myer, Chief, Division of Cooperative Relations and Planning, Soil Conservation Service.

[2] For an extended discussion of the use of grants-in-aid as a means of inducing action on the part of States, the reader is referred to V. O. Key (*198*).[3]

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

have something left over in order to build up a cash reserve, to improve his farm, to provide a better education for his children, or to increase his investment, either through increasing his equity in his farm or the size of the farm. American farmers have generally tended to follow systems of farming and to use farming methods that are essentially exploitative and to give only scant attention to the need for conservation. They grow relatively high acreages of soil-depleting crops, usually return only a portion of the plant nutrients removed, and often fail to recognize erosion until it has reached an advanced stage, or until it is too late to save the land.

This process has been characteristic of the history of American agriculture and has resulted in the continued exploitation of the original land resources of the Nation. Lands which were first settled in the seventeenth and eighteenth centuries were soon exhausted, and agriculture shifted to new lands in the same communities; afterward came a gradual movement westward, which culminated in the plowing up of the Great Plains in the decade 1920 to 1930. As long as new and cheap land was available, little attention was paid to the constant wearing out and abandonment of farm lands and the shifting of farm population. But with the cessation of the westward movement, the restriction of the export market, the downswing in domestic demand from 1929 to 1933, and the increasing frequence of droughts and dust storms in the Great Plains region, the attention of the Nation was suddenly directed to what had been happening to its agricultural land, and the conservation movement broadened to include the conservation of private land.

The first national movement in this direction was in the original commodity adjustment programs which were authorized by the Agricultural Adjustment Act, approved May 12, 1933. This act was primarily designed to control the production of corn, wheat, cotton, and tobacco, and was only indirectly designed to encourage conservation. But it was realized within the Agricultural Adjustment Administration that conservation was a basic agricultural problem and that both conservation and production control needed to be considered in any continuing agricultural program. The soil resources of the country were being steadily depleted, and although production was well in excess of domestic demand, there was every reason for endeavoring to maintain the agricultural plant in such a manner as to increase or at least maintain potential producing power, in order that future increases in demand might be adequately and efficiently met. As a result, the adjustment programs of the Agricultural Adjustment Administration were designed to encourage the shifting of acreages diverted from the chief soil-depleting crops to crops or uses which would conserve or improve the soil and check or prevent erosion. In October 1935, President Roosevelt declared that any permanent agricultural program required a broadening of "present adjustment operations so as to give farmers increasing incentives for conservation and efficient use of the Nation's soil resources" and urged that every effort be made gradually to rework or transform the temporary agricultural program then in operation into a long-time agricultural program.

While the need for a long-time program under which agricultural conservation and production adjustment both would be considered

was being discussed, the Supreme Court declared the acreage-adjustment and processing-tax sections of the Agricultural Adjustment Act unconstitutional in the Hoosac Mills decision. This led to the enactment of the Soil Conservation and Domestic Allotment Act in February 1936. Under this act, agricultural conservation became a primary objective and provision was made for making conditional grants, which were the equivalent of the original rental or benefit payments except that no contracts were required, to farmers and ranchers for positive performance in improving and conserving farm and range land.

The 1936 agricultural conservation program was a transition program. Administered by the same agency and by the same county committees as the original agricultual adjustment programs, it was necessarily related to those programs, but the emphasis was changed. Grants were conditioned upon both the shifting of acreage from soil-depleting crops to soil-conserving crops and the carrying out of soil-building practices in accordance with certain specifications and within limits laid down by the Administration. Approximately 4,000,000 farmers cooperated in the 1936 agricultural conservation program, and it is estimated that approximately two-thirds of the total cropland of the Nation was covered by applications for grants. Approximately 31,000,000 acres were shifted from soil-depleting bases under the program, and soil-building practices that qualified for payment were carried out on approximately 53,000,000 acres on participating farms, or perhaps twice the acreage on which such practices would normally have been carried out. Altogether, more than $375,000,000 was paid to farmers in connection with the agricultural conservation program for 1936.

The agricultural conservation program for 1937 was similar to the agricultural conservation program for 1936. The 1937 program, however, carried a number of provisions which provided for a wider participation than under the earlier program. These changes were such as to appeal especially to dairymen, range cattlemen, and commercial truck and orchard growers, and resulted in wider distribution of participation than was the case in 1936.

For 1938, the agricultural conservation program is considerably different from the program of either 1936 or 1937. In general, it is proposed that a maximum grant or payment be established for each farm. In addition, a soil-depleting limit or goal and a soil-building goal will be established for each farm, in order to maintain a desirable balance between the several classes of crops and to encourage efficient farm management and soil conservation, and the grants will be conditioned upon each farmer reaching the goals established for his farm.

The experience gained in 1936 and 1937 with conditional grants as a means of encouraging conservation indicates that there are still a number of questions which must be further considered before the most effective use of this approach can be achieved.

Should the grants be proportional to the sacrifices made by the individual farmers, or should they be made for carrying out certain practices or following certain systems of farming which many farmers would normally carry out or follow even if the program were discon-

tinued? In general, it is believed that payment rates should be set at such a level as to recompense farmers for somewhere between two-thirds and three-fourths of the cash or extra out-of-pocket costs or sacrifices involved, provided the acreages shifted or the practices carried out are in addition to those which farmers would normally carry out. The additional practices obtained or the extent to which acreages are actually shifted depends in large part upon the manner in which bases or goals are established. The first bases established under the Agricultural Adjustment Administration were almost strictly historical—that is, they depended on what the farmer had actually done in the past—and it is probable that the shifts made in the first year or two were almost all shifts which would not normally have occurred. As the adjustment programs continued and as the emphasis was shifted from production control to soil conservation, it was realized that the historical base resulted in many inequities to individual farmers and was too rigid for use in a continuing program, so emphasis has been shifted gradually toward establishing bases that depend on the systems of farming needed in the interest of agricultural conservation and good farm management.

The program for 1938, which would involve the establishment of goals rather than bases, represents a still further shift in this direction. The ideal base is, of course, that acreage or that system of farming which the farmer would normally follow in case the conditional grants or benefit payments were not offered. Owing to the personal characteristics of farm operators and the variation in both physical and economic conditions as between individual farms, it is practically impossible for any community or county committee to establish bases for each farm that will precisely measure up to this ideal. It is believed, however, that a system of bases or goals can gradually be evolved which will be equitable as between individual farms and which will tend to approximate the ideal standard. Some portion of the grants under the current agricultural conservation program are going, and perhaps should continue to go, to farmers who would normally follow reasonably well balanced and conserving systems of farming even though an agricultural conservation program were not in effect. However, the bulk of the grants should very definitely be used to encourage additional conservation.

Can such grants be expected to be effective in areas which are essentially submarginal or in areas where the size of the farm is so small as to force continuous overutilization of the land? Beyond doubt the use of the conditional-grant approach that has been employed by the Agricultural Adjustment Administration since 1936 cannot be expected to solve the conservation problem in areas where the problem is so acute as to necessitate the return of the greater portion of the land under cultivation to grass or forest, or in areas where a material increase in the size of the farm is needed in order to provide reasonably full employment and a minimum standard of living for the agricultural population. But it is possible that the conditional-grant approach can be used to ameliorate conditions in such areas until other means of obtaining the needed adjustments become available, and, if properly coordinated, they may well continue as a part of the general program for improvement.

The question is also raised as to how long conditional grants must be continued in order to bring about a stabilized condition with respect to agricultural conservation, or whether education and technical advice and services can eventually be used to supplant the conditional-grant approach. Experiment station, extension service, and Smith-Hughes work in agriculture all are directed toward a continuing and interlocking research and educational program which will give farmers the benefit of social and scientific research, and which will tend to encourage good land utilization and agricultural conservation. There is, however, constant conflict between the short-time interest of the individual and the long-time interest of the group, and it is doubtful if this conflict can be resolved by education alone, especially on tenant-operated and heavily mortgaged farms where the tenants or farmers have little choice but to follow their short-time interest. An educational program supplemented by the offer of technical advice and needed materials and services such as are now supplied by the Soil Conservation Service may eventually be all that is needed. But in periods of low prices or general depression the need for immediate income will force the great majority of individual farmers toward exploitative systems of farming unless this tendency is offset by some remedial program. Certainly there can be no question that in working out such a program serious consideration should be given to the use of the conditional-grant or benefit-payment approach as a supplement to, or in combination with, such other devices as may be used.

TECHNICAL AND OTHER SERVICES

With the recent development of national interest in soil conservation it has become apparent that individual farmers need very definite assistance in formulating and carrying out soil-conservation plans, and that, in light of the relationship of the soil resource to national welfare, the responsibility for rendering this assistance properly devolves upon the States and the Federal Government.

Assistance is now being provided to individual farmers by the Soil Conservation Service, the Civilian Conservation Corps, and the Tennessee Valley Authority in connection with the national program of soil conservation. Such services are a relatively recent development and are supplemental to the educational program of the agricultural Extension Service and the benefit-payment program of the Agricultural Adjustment Administration.

For the most part, up to the present time, technical services and other assistance to individual farmers have been confined to the watershed project areas that form the skeleton structure of the Soil Conservation Service demonstrational program, and to the areas worked by Civilian Conservation Corps camps assigned to the Service. Approximately 170 watershed demonstration project areas and 400 C. C. C. camp areas are now included in the program.

Within the watershed demonstration project areas, detailed erosion surveys showing the degree of erosion, soil type, degree of slope, and land use have been made as a basis for the formulation of work plans. A technical staff, consisting usually of soil conservationists to develop individual farm programs, engineers, agronomists, foresters, and in some instances wildlife specialists, is attached to each project area.

The aim of this type of work is to establish a complete demonstration of effective erosion-control practices through the cooperative application of a coordinated land-use and soil-conservation program within the area.

This objective is sought through active cooperation with the individual farm owners and operators of the area. The technical staff of the Service works with each cooperating farmer in developing a complete farm conservation plan, which takes the form of an agreement between the Service and the individual farmer. In this agreement the obligations assumed respectively by the two cooperative parties for a 5-year period are set forth. Assistance is rendered only to those farmers who become party to a cooperative working agreement.

Aside from the technical advice and supervision of project staff technicians, contributions made by the Soil Conservation Service under these carefully planned working agreements include certain materials or supplies. Fertilizer may be furnished for a limited acreage of erosion-preventing crops, usually grass or legumes; ground limestone for the same purpose; and new fencing under certain conditions, in order either to encourage the protection or improvement of a soil-holding cover in pastures, range, or wood lots, or to facilitate the relocation of fence lines to accommodate contour cultivation. Seeds or other planting stock not commonly used within the area are supplied in limited quantities in order to develop a thorough demonstration of the erosion-control value of untried crops and to assist in establishing the most useful cover on steep slopes or other badly eroded land retired permanently to erosion-control vegetation.

Various types of equipment are also provided within these areas in order to assure adequate demonstrations of contour furrowing, listing, terracing, gully filling and planting, or the construction of small dams under certain conditions. Likewise, during the past 4 years a large amount of W. P. A. labor has been utilized in various erosion-control operations, including fence building, the rearrangement of fences, building of terrace outlets, construction of check dams and other small dams, timber-stand improvement, the growing of planting stock in nurseries, and similar activities. C. C. C. labor crews from camps engaged in soil-conservation work under the technical supervision of the Service are used whenever possible to carry out the more difficult and laborious work involved in the farm-treatment program of the projects and camp areas.

As a general rule, farmers will contribute to the extent of at least 50 percent of the cost of the program during a 5-year period. The experience of the Service indicates that the willingness of farmers to contribute increases markedly as the program is more thoroughly understood. In many areas, farmers are now being required to meet all material and equipment costs in return for technical assistance and a small amount of labor help from the Service.

The Tennessee Valley Authority, under a memorandum of understanding with the Department of Agriculture and with individual State agencies, is cooperating with the States in providing technical personnel to supervise educational work within counties of the T. V. A. territory and is providing phosphates to local associations and committees, to be used by farmers under the supervision of the State

extension services and the State experiment stations in growing erosion-resistant crops other than row or cash crops, particularly legumes, grasses, and vegetative cover of similar type. Within the past year, an arrangement has been worked out between the T. V. A. and the Agricultural Adjustment Administration whereby phosphates, to be used in certain soil-building practices approved by the A. A. A., the State extension service, and the State committee, may be provided the farmer in lieu of cash payments.

From the standpoint of the Soil Conservation Service, assistance and technical services of the type discussed above have been found desirable for a number of reasons.

(1) An effective program of soil and moisture conservation on any farm involves the adoption of a carefully devised and comprehensive plan of land use and land treatment. This calls for mapping the farm, working out coordinated plans for the application of conservation measures, and extreme care as well as certain technical knowledge in the execution of these plans. Consequently, it has been essential that adequate technical supervision be provided for the work undertaken cooperatively by the Service and individual farmers in the demonstration project areas.

(2) During the period following 1930, when the program of the Service was getting started, it was necessary to furnish the materials required for an effective demonstration of soil and moisture conservation. These materials have been furnished only in small quantities on individual farms where it would have been difficult for the farmer to provide them because of the cash outlay involved in a period of economic distress. In some cases these material contributions by the Service have been regarded in the light of inducements to farmer cooperation, but they were also a necessary step in the establishment of effective demonstrations.

(3) During the early period when Service operations were carried on with relief funds, it was essential to speed up individual farm planning and obtain adequate cooperation on the part of farmers in order to utilize available funds in the constructive employment of relief labor. Consequently, considerably more materials, supplies, equipment, and labor were provided by the Service during this period than at present.

(4) Certain benefits have undoubtedly accrued from the practice of providing services and materials, rather than cash grants, in that farmers had no alternative to using materials such as seed, fertilizer, etc., in a beneficial and constructive manner. Consequently, the contribution of such material provided the opportunity for establishing a demonstration of benefit both to the recipient and to other farmers, which otherwise could not have been easily attained. For example, a greater interest in saving home-grown seeds of the type not normally grown in the area has resulted, and an increase in acreage of erosion-resistant crops has been speeded up. In one case in Arkansas, the Service in an experimental pasture demonstration in 1935 furnished a cooperator with 16 pounds of Italian ryegrass seed for a small plot with the idea that the farmer would increase the acreage put to such use. The cooperator furnished sufficient hop clover seed to mix with the ryegrass. A seed-harvesting demonstration was held on the farm the following spring. By 1937 the cooperator had 12 acres planted to

this mixture from the seed saved from his original crop, and in addition had supplied small quantities of the seed to other farmers. The grass crops also aided in preventing overgrazing of his native pasture. This farmer now plans to add sweetclover and lespedeza to the mixture and to increase the acreage to between 20 and 25 acres in order to improve his crop-rotation system and maintain his crop-livestock balance.

Seed of many native plants which were not previously cultured, such as little bluestem, have been utilized to good advantage in many areas. Grass seed of this type as well as of other native vegetation have been developed in the nurseries and through test plantings.

Special equipment for harvesting some types of valuable native seed is one of the needs that has been only partially supplied.

(5) Materials and services provided by the Service have speeded up the establishment and completion of demonstrations and have brought about quicker adoption of improved practices for erosion control and soil conservation.

(6) Because of the inability of many farmers to furnish heavy machinery immediately for a complete program of erosion control, the Service found it necessary to provide a limited amount of equipment such as tractors, terracing machinery, and tools which in many cases were new to local farmers. These included sod cutters, pasture-furrowing machines, basin listers, long-winged plows, and other large machines. They have been supplied for the purpose of demonstrating their practicable use in a sound and effective program of soil and water conservation. In many areas, where voluntary soil-conservation associations have been formed outside of camp and project areas, county governments and other agencies have cooperated in helping to provide equipment, which has usually been paid for by the farmers of the association through a cooperative plan of reimbursement.

Problems Involved

While services of the type here discussed generally have been highly beneficial and worth while, certain problems have been encountered. Others which might arise if the present plan were to be expanded to any considerable degree without alteration of the basic operating principle can be anticipated.

For example, Federal procurement on a large scale necessarily involves important and essential regulations and procedures. A staff adequate to handle requisitions, inventories, and other administrative details involved in the procurement of materials, equipment, and supplies would be both large and costly.

Of another type is the problem of farmer response to contributions from the Government. In most areas, a full explanation of the essential reason for these contributions has resulted in complete understanding and a willingness on the part of the farmer to assume his full share of the cooperative burden. In some cases, however, farmers have been prone to regard Service contributions purely as inducements and have treated them as such, with little regard for the terms under which they were furnished.

Likewise of considerable moment is the problem of providing Government labor, materials, and equipment for work on private lands. Fully justified under the present program of demonstration, there is

considerable doubt as to the justification for this type of activity on a large scale if the plan were extended to wide areas on other than a demonstration basis.

Possibilities and Recommendations for the Future

The problems of soil and water conservation cannot be adequately solved in isolated work areas. The work must be expanded—made available to a much larger number of farmers and communities. Such an expansion calls at the outset for establishing a basis of cooperation with individual farmers through organizations of their own formation under State law. With this in mind, the Department prepared and recommended to the States a Standard State Soil Conservation Districts Law.[4]

The development of the soil conservation districts plan provides an admirable mechanism for expansion of the soil conservation program beyond the demonstration stage. Working through and in cooperation with such districts, the Federal Government should be in a position to provide necessary surveys, technical assistance in district and individual farm planning, and technical supervision while the work program is being carried out.

Assistance on the part of the Federal Government in providing materials and equipment to the districts, however, should be limited to those things which cannot readily be supplied by the farmers themselves and which will constitute a real contribution to the public welfare. It would seem advisable that services of this type be provided in the future through conditional grants in funds or services to legally organized districts after a complete work plan has been developed and the needs thoroughly analyzed. Federal contributions of this type should be comparatively small in relation to technical services supplied by the Service and should be made available only when the districts provide an equal amount. Such a procedure would assure thorough consideration on the basis of a real need, and should reduce the cost to the Federal Government by placing responsibility on the local district for purchase and distribution under a procedure jointly agreed upon.

Labor has been an important contribution to certain types of conservation work in many demonstration areas. Where proper working plans have been developed and adequate technical planning and supervision provided, C. C. C. labor can be utilized effectively to supplement the labor of the individual farmer and speed up the application of conservation measures. If C. C. C. labor is to be utilized for soil-conservation work in the future, it would seem highly desirable that camps be located within the boundaries of legal districts where this type of labor can be used to develop a completely coordinated program under competent technical supervision. If other types of relief labor are available, procedures could be worked out for their utilization in the same manner as a part of a public works program.

Through the cooperation, then, of individual farmers, soil conservation districts with definite legal and local responsibility, and a State committee which would include representatives of the proper State technical agencies cooperating with the Soil Conservation Service and

[4] See The Remedies: Policies for Private Lands, Soil Conservation Districts Laws, p. 248.

other Federal agencies, a thoroughgoing coordinated program of soil and water conservation can be developed with opportunity for equitable contributions from each of the agencies involved. Under such a plan, services and assistance of the type discussed here, including technical services, materials, equipment, and labor, can play a tremendously important part, with major emphasis, perhaps, on technical services.

IF THERE WERE *any simple, easy, and obvious solution of the problem of achieving greater economic stability, it would have been applied long ago. Instead, this is the field where there is the most controversy and disagreement. Yet what is done with the soil depends, largely and in the long run, on the solution to this problem. In trying to reach a solution for agriculture, there is today an attempt to achieve a better balanced production through such measures as commodity loans, crop insurance, and acreage control. These measures are discussed in the first part of this article. But agriculture is only part of the general economy; it cannot escape the effects of inadequate distribution of purchasing power, unemployment, the relations between labor and industry, industrial prices, trade practices, tariffs, and trade barriers. The last part of the article attempts to bring out these relationships and suggests some of the possible choices.*

The Remedies: Economic Stabilization

By O. V. Wells *and* Bushrod W. Allin [1]

AGRICULTURAL ADJUSTMENT, AGRICULTURAL INCOME, AND LAND UTILIZATION

SO FAR this series of articles has been chiefly concerned with direct methods or inducements that seem best calculated to bring about better land use, such as rural zoning, soil conservation by State action, tax reforms, conditional grants, and Government purchase of submarginal land. But the indirect approach to the land-use problem through efforts to stabilize prices and to increase and maintain agricultural income at a reasonable level must not be overlooked.

Agriculture has long been an occupation in which variable prices and uncertain yields have meant hard work and so low a standard of living as to force great numbers of farmers toward exploitative systems of farming in order that mortgages might be paid and some degree of security attained, or in order that a sufficient stake might be laid aside to allow the farmer or his children to shift to some form of urban occupation. As a result, measures designed to stabilize

[1] The section headed Agricultural Adjustment, Agricultural Income, and Land Utilization is by O. V. Wells, Principal Agricultural Economist, Production Planning Section, Agricultural Adjustment Administration, and the section headed Governmental Action for General Economic Stabilization is by Bushrod W. Allin, Special Representative, Office of Land Use Coordination.

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prices, to insure yields, and to increase and maintain agricultural income offer an attack upon one of the fundamental causes of improper land utilization. To the extent that such measures are successful, they should lessen the incentive toward soil mining that has so long dominated agriculture, should help stabilize land values, and should tend to reduce the need for, or serve as a supplement to, the more direct approaches to the problems involved.

Perhaps the best way to consider this indirect approach is to trace through the several steps that might be involved in a well-rounded agricultural adjustment and ever-normal granary program, as developed to a considerable extent in the Agricultural Adjustment Act of 1938.

So far as its direct effect upon prices and agricultural income is concerned, the first step in such a program would be voluntary acreage control. This has been considered under the heading of Conditional Grants (p. 279). Experience since 1933 has indicated that voluntary acreage control may be expected to result in moderate adjustment of crop acreages, especially when prices are relatively low and current stocks of the commodity in question are relatively high. But it cannot be expected to result in an exact control of the total amount of production moved to market in any given season, nor can it be expected to result in radical changes in acreages, especially in areas where the alternative uses of the acreage diverted from the cash crops are limited. For these purposes, two additional steps are needed.

To equalize the flow of commodities into the consuming market, some device is needed that will tend to encourage the building up of reserve stocks in years of high yields and the depletion of these stocks in years of low yields—the ever-normal granary function. To some extent, farmers, warehousemen, and traders tend to hold increased stocks in years when production is high and prices are relatively low, and to deplete these stocks when the situation is reversed. However, the stabilizing effect of this normal type of carry-over is not usually great enough to offset the year-to-year differences in yields, except in the cases of tobacco and cotton. Commodity loans and crop insurance are the devices most commonly suggested for encouraging additional storage, and provision for both of these was included in the Agricultural Adjustment Act of 1938.

The equalizing effect of commodity loans would be obtained through offering loans equal to or slightly above the current market price in years when yields were high and prices depressed, on such commodities as corn and wheat, with the commodity itself serving as the only security for the loan. These loans would be called or carried forward at about the same rate in years when yields were low and prices high, so that stocks would automatically be decreased. This would tend to equalize the flow into consumption or into the market between years of low and high production.

Crop insurance is designed to accomplish the same result. It is proposed that farmers pay premiums to a crop insurance corporation either in the form of a specific quantity of the commodity insured or in an amount of money that will allow the crop insurance corporation to acquire title to an equivalent amount of the commodity, and that

indemnities be paid in terms of the commodity or its current cash equivalent. This would mean that the crop insurance corporation's reserve or storage stocks would be increased in years when yields were above average and premium payments exceeded indemnities, and decreased in years when yields were below average and indemnity payments were preponderant.

Several successive years of high yields, however, might result in building up excessive stocks, and some form of positive acreage or marketing control would then be needed. Several devices have been suggested for obtaining this positive control. Marketing quotas are provided for in the Agricultural Adjustment Act of 1938, to be put into effect when supplies are extremely large and prices depressed. Under these circumstances, farmers who marketed more than the portion of their production needed for current consumption and exports would be subject to a direct penalty on each excess pound, bushel, or other unit marketed. The marketing quotas would be apportioned among farmers in proportion to the acreage allotments given them under a conservation or voluntary production-control program. These acreage allotments would of course be calculated in terms of the acreage at average yields required to produce the supply of the commodity that, together with the carry-over, would tend to adjust supplies to a normal or desirable level relative to the prevailing domestic and export demand. This device would restrict the quantity of the commodity moving into market and serve as an added inducement to farmers to enter into the voluntary acreage-control program.

There is much yet to be learned in connection with the successful coordination and working out of the several steps just described. But assuming that such a plan can be successfully developed and administered, the results may well be expected to contribute to better land utilization. The successful operation of the several steps should tend to encourage conservation directly through encouraging a shift from soil-depleting to soil-conserving crops, and indirectly through raising and stabilizing the farmer's standard of living so that he could devote more attention to soil conservation; stabilizing land values and working toward a more rational debt structure; and stabilizing farm occupancy, thus increasing the farmer's long-run interest in soil conservation and good land utilization.

The development of any acreage-control program would be dependent, of course, upon the need for controlling the acreage in the chief cash crops, which also happen to be the chief soil-depleting crops, in that they are the crops which place the heaviest drain on the soil, both in terms of their nutritive requirements and because they require the tillage methods that are most likely to encourage erosion. Since any acreage-control program should be associated with a conservation program, it is natural to assume that the acreage shifted out of such soil-depleting crops as corn, cotton, wheat, and tobacco would be shifted into soil-conserving crops or permanent pasture, except where such acreage might be needed to produce feed and food crops for home consumption. Farmers should also be encouraged to use conserving practices or methods of cultivation on their soil-depleting acreages, especially in areas where erosion is a serious problem.

An important contribution toward better land utilization that might be expected to result from such a program would be an improvement in farm income which would allow farmers a greater surplus above minimum living costs than they have usually obtained in the past. This could be used in part for raising the standard of living of the farm family and in part for improving and conserving the productive resources of the farm. It is extremely difficult for a farmer to maintain his acreage of soil-depleting crops at a reasonable level or to carry out needed conservation practices, such as terracing, sowing soil-conserving crops, and pasture improvement, when his income is hardly enough to provide a minimum standard of living, pay his taxes, and carry his debt.

To the extent that such a program tended to stabilize land values it would remove one of the underlying causes of improper land utilization. So long as yields, prices, and production vary, it is natural that land values should vary, since they are dependent upon the efforts of farmers and others to estimate and capitalize the income derived from the land. Whenever several good years occur in succession land values tend to rise, and both the acreage of land changing hands and the debts incurred are materially increased. As soon as yields, prices, and income decline, land values fall sharply and the debt burden on the land is automatically increased. Farmers are then forced toward intensive systems of farming without regard to the effect upon the fertility of the soil or the eventual value of the farm land. Stabilization of agricultural income would tend to correct this situation, especially in the better farming sections where good yields can be obtained over an indefinite period provided proper cultural methods are followed.

It is not to be inferred from the foregoing discussion, however, that such a program would result in the complete stabilization of agricultural prices and agricultural income, or that it would be simple to carry out. We have had considerable experience with acreage control since the passage of the original Agricultural Adjustment Act in 1933, but much remains to be learned, especially with respect to the marketing-quota approach. The question of how to prevent the capitalization, in the form of increased land values, of more than a reasonable proportion of any increases in income needs to be considered and will offer a difficult problem. The commodity-loan program could easily be abused. Producers will want to obtain loans at as high a level as possible, but loans and prices will have to be maintained at a level fair to consumers as well as producers if the program is to be successfully operated.

Consumer demand affects agricultural prices, and this is an element that is not subject to farm control. A severe depression such as that beginning in 1929 would necessarily result in a considerable decline in agricultural prices and agricultural income, even though the program outlined above might be in operation. Again, declines in foreign demand or the imposition of additional trade restrictions in other countries, such as tariffs and quotas, would result in a smaller market and a lower price for the agricultural commodities we export. This means that farmers should be interested in attacking those factors associated with instability which are outside the agricultural field.

GOVERNMENTAL ACTION FOR GENERAL ECONOMIC STABILIZATION

Production control, crop storage and loans, and crop insurance can make important contributions toward a more stable economy, but maximum possibilities in this direction cannot be realized by such measures alone.

Vital also, in any complete mosaic of governmental policies for promoting national security, are policies with respect to labor and business. These require many different types of legislation, including those relating to wages and hours, unemployment and old-age insurance, fair trade practices, industrial prices, money, taxation, and tariffs. Though it is beyond the province of this Yearbook to make specific recommendations for action in these fields, a program for better soil use is likely to be wholly inadequate if its framers are not at least aware of the necessity for integrating soil policy with economic and social policies ordinarily regarded as more or less unrelated to the soil.

This emphasis upon comprehensive governmental action to promote economic stability in the interest of better soil use is not intended to imply that there is no need for action by individuals and by organized groups other than the Government. The Government is a social institution, which means that like all other institutions it involves collective action in control of individual action. Theoretically, governmental policy is supposed to be motivated by the will to promote the general welfare, but at many points it has been controlled by various commercial and industrial groups for the promotion of narrower interests. To offset some of these interests, effective action by labor unions, farm organizations, and consumer groups is indispensable to a balanced organization of government. Otherwise the government cannot be truly democratic, and socially desirable legislation either will not be adopted, or it will fail short of serving the general welfare because of half-hearted execution.

To many it may seem a far cry from soils to wages and hours, trade practices, and industrial prices; but these things are all aspects of the problem of industrial stabilization, which has a very direct relation to soil use. One of the most conspicuous examples of this relationship is to be found in the ebb and flow of labor in the Lakes States between the manufacturing and mining communities and submarginal land areas. What is conspicuously true in these instances is also true for industry and agriculture generally. Agriculture has to bear a disproportionate share of the burden of industrial unemployment during a depression when in too many instances submarginal lands are the haven of refuge for the unemployed. Yet the urban worker cannot logically be denied the privilege of using submarginal lands if better alternatives are not provided.

Stabilization of nonfarm employment must be brought about on a basis that will provide employment opportunities for the natural annual increase in the farm population if the additional population is not to dam up on farms, in many places in inverse ratio to the quality of the soil. If technology is advancing at such a rate that industry will not or cannot employ the national labor force at customary hours

of work, it will be necessary either to take some such step as reducing the hours of work by law in order to spread the available work among the available workers, or to take care of an unemployed class permanently by such means as C. C. C. camps or W. P. A. projects. The latter alternative, with its implication of a permanent level of poverty, may be less costly to industry but more distasteful to labor. Under conditions of increasing output per man-hour, permanent and full employment in private industry can be realized only by increasing real wages per man-hour so that a balance between production and purchasing power is maintained. It is to help insure this result that we find increasing sentiment for minimum wage laws.

Inseparably linked to the broad measures here considered is a complex of national fiscal policies and international relations affecting tariffs. It may seem a long distance from soils to tariffs, but when a tariff policy contributes to the stagnation of international trade, it keeps producers of many export commodities at a disadvantage, helps to improverish agriculture, and thereby causes misuse of land, for impoverished farmers readily become soil miners. Remedial action to promote sound land use, therefore, might well include efforts to lower international trade barriers by such means as reciprocal trade agreements.

But more is needed than mere restoration of international trade. We had international trade during the 1920's, but it was not reciprocal, and for that reason it did not last. As long as the United States was a debtor nation we could continue to sell abroad more goods than we imported, or to maintain a so-called favorable trade balance; but now that she is a creditor nation and already has a large share of the world's gold, it will be difficult if not impossible to collect the debt owed us if we refuse to import more than we export. And even if debts are cancelled, we must be prepared to accept an equivalent amount of goods in payment for exports if our farmers and manufacturers are to continue selling their surpluses abroad.

Fundamentally, therefore, the problem of achieving a stable and ascending scale of material prosperity is that of steadily increasing the per-capita domestic consumption of goods, whether or not international trade is restored. If international trade in competitive products is greatly enlarged on a reciprocal basis, large segments of American industry will have to reduce prices and share the domestic market with foreigners. The only alternatives for maintaining a rising plane of living by increasing mass purchasing power are for these same segments of industry either to raise wages or to lower prices without lowering tariffs and retain for themselves an expanded domestic market.

In either case, the problem is both to maintain an adequate distribution of the national income and to augment the total amount of it. That these two aspects of the problem are closely related is clearly revealed when efforts are made during a serious depression to stave off complete economic collapse. The Government borrows and starts "pump priming" by forcing purchasing power out through relief, public works, and other channels. Obviously borrowing cannot be continued indefinitely, and the assumption is that a period of prosperity will follow when the Government can reduce its debt.

Government borrowing and spending is an emergency procedure for reviving industry by redistributing purchasing power. In the long run, however, any tendency toward too great a concentration of wealth and income in too few hands must be checked by permanent measures. Among the means to counterbalance such a tendency are a rational application of income taxation at progressive rates, central control of money and credit, operation of permanent machinery for intermittent public works programs, full enforcement of adequate labor legislation, and other related procedures like the long-time provisions of the agricultural adjustment programs.

Such efforts at economic stabilization may be described in other terms as attempts at least to mitigate the extreme effects of the business cycle. Admittedly, the problem of reducing the major fluctuations in the general price level is a difficult one, mainly because they are part of the system. But that the system can be changed and has been changed in various ways is apparent to all informed observers. Income taxation was not a part of it before 1913; and until very recently, the right of workers to bargain collectively with their employers, through representatives of their own choice and without interference from employers, was not firmly established.

In an age of dictators, monopolies, and mass production, collective bargaining has additional significance for all advocates of democracy as a technique in achieving such aims as sound land use. Greater economic stability and a wider distribution of purchasing power as means of encouraging soil conservation and better land use might conceivably be put into effect by either authoritarian or democratic processes. If, therefore, we would preserve democracy as well as the soil, we shall continue to improve the system of collective bargaining through nongovernmental organizations of farmers, workers, and other groups that can function effectively in both economic and political fields. We shall deliberately encourage this process as one of the essential characteristics of democracy and shall steadfastly avoid resorting to government fiat backed by physical force as a means for resolving economic conflicts and promoting the general welfare.

UNDER THE AMERICAN FORM ***of democracy, the citizens of this country must look not only to the legislative and executive branches of the Government, but also to the Supreme Court for final authority for broad social and economic action as well as for action more directly related to soil use. It is the Court's decisions with respect to legislative and executive acts that determine whether and how the Government shall promote better soil use. As a very practical matter, therefore, those who would frame either soil legislation or proposals for economic and social changes indirectly affecting soil use must always keep in mind the probable impact of the judicial process. The final article in this section, dealing with soil and the law, shows how the lawyer has to approach his problems. The views expressed in this article are the views of the author and not necessarily those of the Department.***

The Soil and the Law

By Philip M. Glick [1]

THERE is a frontier on which land-use programs confront the law. It is the purpose of this article to explore this frontier—to indicate some of the problems that must be solved if remedial measures for the better handling of our soil resources are to be translated from paper programs to living institutions, that is to say, are to be enacted into law, administered, and made effective.

Let us recall the nature of the remedial measures most frequently proposed. They include: Control of soil erosion on private and public lands; retardation and reduction of water run-off on the watersheds, in aid of flood control; an agricultural production safeguarded against oversupply as well as against shortage caused by drought or other natural agencies; retirement of submarginal land from cultivation or other improper use, and its devotion to uses in the public interest; assistance to farm tenants to enable them to become owners; readjustment of the relationships of farm landlord and farm tenant, to improve the tenure system; better management of grazing on private and public range lands; rural zoning to correct maladjustments in land use; and revision of tax structures to encourage proper land use and discourage the reverse. These are the high lights.

These proposals involve action by the Government, as distinct from private action. It should be noted further that they involve at least three types of Government activity: (1) Direct administration of lands by the Government. Instances are the national and State forests and parks, the public domain, Indian reservations, wildlife refuges.

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(2) Public regulation of private land use. *Instances—zoning ordinances*, land-use regulations adopted by soil conservation districts, statutory requirements applicable to farm leases. (3) Subsidies paid by the Government on the condition that stated land-use adjustments are made. Familiar instances are the Agricultural Adjustment Administration benefit payments and the assistance given by the Soil Conservation Service to farmers within erosion-control demonstration projects. For some purposes it will be important to break down this classification in terms of the level of government—national, State, or local—concerned.

Under the political theory which is dominant in this country, the functions of government are considered to be divisible into three parts—legislative, executive, and judicial. Because of this theory our constitutions, both national and State, provide for a separation of these governmental functions among independent agencies, generally prohibiting "invasion" of the field of each by either of the others.

An action program that is to be undertaken by the Government necessarily involves, therefore, (1) the formulation of the program and its enactment into law as a statute; (2) the enforcement and administration of the statute by the executive; and (3) the interpretation and application of the statute, in disputed cases, by the courts. The farmer on the land, and the scientists and economists concerned with action programs dealing with land use, confront the law, therefore, on these three sides.

OUR FEDERAL SYSTEM—POWERS AND LIMITATIONS

In the United States, land-program administrators must consider not 1 but 49 sovereigns. The Federal Constitution establishes the United States as a government of limited (delegated) powers. The United States may exercise only those governmental powers granted, expressly or by necessary implication, in the Federal Constitution. The several States, on the other hand, are governments of inherent general power. They may exercise any governmental power not forbidden them, again either expressly or by necessary implication, either in the Federal or in the State Constitution. It results that, for a Federal statute to be demonstrated to be within governmental power one must point to language conferring the power, while a State statute must be deemed to be within governmental power unless one can point to a prohibition of the exercise of such power.

The legislative field open to Congress is defined in section 8 of article I of the Federal Constitution, as supplemented by provisions in several other sections as well as by the amendments later adopted. The powers conferred upon Congress that are relevant to the action programs here referred to may be listed as follows: Congress has power—

(1) To collect revenues by taxation;

(2) To spend the proceeds of taxation "to pay the debts and provide for the common defense and general welfare of the United States";

(3) "To regulate commerce with foreign nations, and among the several States, and with the Indian tribes";

(4) To "dispose of and make all needful rules and regulations respecting the territory or other property belonging to the United States"; and

(5) "To make all laws which shall be necessary and proper for carrying into execution the foregoing powers, and all other powers vested by this Constitution in the Government of the United States, or in any department or officer thereof."

On the asset [2] side of the ledger of governmental power we may, then, enter these powers for the Nation, while we may make an entry of inherent general governmental power for each State. For the liability [2] side of the ledger we must note certain important limitations upon the exercise of governmental power.

In the case of the action programs with which we are here concerned, the most important of the limitations placed by the Federal Constitution upon the Federal Government are the following:

(1) No "person" may be "deprived" of "liberty" or "property" "without due process of law."

(2) There is an inherent limitation in the second grant of power mentioned above; the "spending power" (aside from its use for paying the debts and providing for the common defense) must promote the "general welfare." For no other purpose may the proceeds of taxation be spent.

(3) The tenth amendment recites that "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States, respectively, or to the people." (This may not appear to be a limitation upon the exercise of those powers which are delegated, but it will be seen in the course of the argument that it has become such a limitation.)

(4) The Congress, the President, and the courts are each forbidden to delegate to either of the others any of the powers conferred, and no one of the three may invade the field assigned to either of the others. (This limitation is not to be found in any express provision of the Constitution, but has been derived by the Supreme Court from the structure of the document as a whole.)

Upon the States the Federal Constitution imposes the following principal limitations relevant to the remedial measures here discussed:

(1) No State may "deprive any person of * * * liberty, or property without due process of law."

(2) The proceeds of taxation may not be expended upon other than a "public purpose." (This has been judicially derived, not from any express provision of the Constitution, but as an implication of the provision that no State may deprive any person of property without due process. Many State constitutions, however, make this limitation explicit.)

(3) No State may "deny to any person within its jurisdiction the equal protection of the laws."

The State constitutions generally repeat the limitations on the exercise of governmental power by the States summarized above from the Federal Constitution. Many impose additional limitations, a few of which should be here noted:

(1) All but a very few, expressly or by judicially derived implication, prohibit delegation of power from one department of the government to another, and invasion of the respective spheres. (It is important to note that the Federal Constitution does not require separation of powers for the State governments, although it does require such separation for the Federal Government.)

(2) The constitutions of 10 States prohibit either the State or political subdivisions of the State, or both, from engaging in "works of internal improvement"; or impose limitations on such action.

(3) The constitutions of 45 States prohibit the "lending or donating," by the State or political subdivisions, or both, of credit, money, or property to or in aid of private persons.

Another item should be entered on this ledger. Under section 10 of article I of the Federal Constitution, two or more States may enter

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[2] The terms "asset" and "liability" are used, of course, only in their immediate sense. It is not intended to deny that a particular limitation upon government power may be desirable, and hence—from the citizen's point of view—an asset rather than a liability.

into an agreement or compact, but only with the consent of Congress.

It will be obvious that if each of the remedial measures named above were to be discussed, to indicate what governmental powers are involved in each and what constitutional limitations are applicable, this section would be unduly prolonged. Two of these remedial measures, however—the State soil conservation districts laws for erosion control (including flood-control work on the watersheds), and the Federal program of agricultural adjustment—present rather characteristic pictures. They involve most of the legal problems common to the other action programs. The discussion may therefore be confined to these programs.

STATE SOIL CONSERVATION DISTRICTS LAWS

The provisions of the Standard State Soil Conservation Districts Law and of the statutes modeled on it, which have been adopted in 22 States, have been summarized elsewhere in this Yearbook.[3] These laws provide for the organization of soil conservation districts as governmental subdivisions of the States, with power to assist farmers in carrying on erosion-control operations and to enact into law land-use regulations needed for erosion control.

State or Nation

The initial problem that confronted the drafters of the standard act was: Should the statute be drawn in form appropriate for adoption by the Federal Congress, or to be submitted to the State legislatures? This basic problem occurs in the consideration of every proposal for government activity, whatever its nature. In the present case there are weighty considerations of policy on the side of providing for the program in national rather than in State legislation. Nature has divided the United States into 76 major drainage basins or watersheds. An excellent case can be made out, therefore, for organizing each of these drainage basins into a single soil conservation district. Since nearly all these drainage basin boundary lines cut across State lines, the several States cannot by separate statutes organize these 76 districts. This important consideration of policy had to be decided on wholly other grounds, however, because of the strong likelihood that the courts would conclude that the proposed statute does not, as a matter of law, fall within the powers which Congress may exercise.

It is true that the Congress may spend public moneys to promote the general welfare and hence to finance erosion-control operations.[4] This it may certainly do upon Federal lands and even upon privately owned lands to the extent that the landowner consents to the performance of such work. Since it is proposed, however, that the districts shall have authority to supplement financial assistance to farmers by enacting into law land-use regulations for erosion control to be binding upon all lands within the district, some regulatory power in the Federal Government must be pointed to. The summary given above indicates that the only relevant regulatory power seems to be the power to regulate foreign and interstate commerce. The Supreme Court

[3] See p. 248. The reader is warned that much of the ensuing discussion may be difficult to follow unless the summary of the standard act is read in connection with it.

[4] This issue is examined as part of the discussion of the agricultural adjustment program, p. 305.

has held that the power to regulate interstate commerce includes the power to promote transportation and navigation.[5] It may therefore well be argued that on the watersheds of navigable streams Congress may regulate private land use under the commerce power—since this land use will affect erosion and the erosion may interfere with transportation on the streams. There is so little material available in court decisions in this field, however, that this conclusion cannot be drawn with certainty.[7] Moreover, it is necessary, in any event, that the land-use regulations of the districts be applicable to all erodible lands. Erosion is not confined to the watersheds of navigable streams. It was decided, therefore, that the statute should be drawn for State rather than Federal action. As has been pointed out, the States have inherent general governmental power, and the statute may therefore be enacted by the State legislatures—but it will be necessary to avoid violation of any of the limitations upon the exercise of State governmental power above listed.

The constitutionality of the State soil conservation districts laws has yet to be determined by the courts. Decisions of the United States Supreme Court and of the several State supreme courts indicate, however, the nature of the principal constitutional challenges that may be directed against this legislation. It may be argued (1) that the enforcement of land-use regulations on private lands will deprive the owners of those lands of liberty and property without due process of law; (2) that any State funds appropriated to finance the work of the districts, particularly to the extent that work is done with public money on private lands, are being expended for a private rather than a public purpose; (3) that legislative power is being improperly delegated by the legislature to the State committee, to the district supervisors, and to the land occupiers who are to vote in the referenda; (4) that there is a failure to provide "equal protection of the laws"; (5) that the State is entering the forbidden field of constructing "works of internal improvement"; (6) that the credit of the State is being lent or donated in aid of private persons; and (7) that some provision of the State constitution, express or implied, prohibits the organization of new governmental subdivisions. Other limitations also may be urged, derived from either the Federal or the State constitutions, but this list includes the more important arguments. Only the three objections first mentioned will be here discussed.

Due Process and the Police Power

Two quite well established constitutional doctrines are relevant on the question whether the proposed land-use regulations can be said to deprive landowners of "liberty" or "property" "without due process of law." On the one hand the guaranty of due process is held to protect the individual from interference by the State with the freedom

[5] With few exceptions, no cases will be cited in this discussion, since this material is addressed primarily to nonlawyers. Those interested in case references on this part of the material may consult a publication of the Department of Agriculture, 1936 (*436a*),[6] A Standard State Soil Conservation Districts Law, which contains the text of the standard act and the opinion of the Solicitor for the Department on its constitutionality.

[6] Italic numbers in parentheses refer to Literature Cited, p. 1181.

[7] It should be noted that what is said in the text is limited to the question of the constitutional power of Congress to regulate private land use for the control of soil erosion. Where a congressional enactment seeks to regulate land-use practices to the extent necessary to regulate commerce in agricultural commodities, an entirely different question is presented. That question is touched upon below in the discussion of the agricultural adjustment program.

with which he may carry on operations upon land he owns. On the other hand it is held that the guaranteed freedom is not absolute, and the State may regulate private land use (or other private conduct), where necessary to protect and promote the public health, safety, morals, or welfare. The last-mentioned protective power is traditionally called the police power.

On March 5, 1934, in its decision in the Nebbia case sustaining the New York milk price regulatory statute, the Supreme Court of the United States stated the relationship between due process and the police power most effectively.

> Under our form of government (said the Court), the use of property and the making of contracts are normally matters of private and not of public concern. The general rule is that both shall be free of governmental interference. But neither property rights nor contract rights are absolute; for government cannot exist if the citizen may at will use his property to the detriment of his fellows, or exercise his freedom of contract to work them harm. Equally fundamental with the private right is that of the public to regulate it in the common interest.

The Court then defined "due process," saying:

> And the guaranty of due process, as has often been held, demands only that the law shall not be unreasonable, arbitrary or capricious, and that the means selected shall have a real and substantial relation to the object sought to be attained.

There is considerable learning to support the view that the guaranty of due process was never intended to be applicable to legislation generally, but was intended to refer only to the procedures by which laws are adopted, administered, and judicially applied. This view would maintain that the idea that a law duly adopted, administered, and applied may nevertheless be lacking in "due process of law" is a contradiction in terms. The above-quoted extract reveals, however, that it "has often been held" that a duly adopted statute will be deemed to be lacking in due process if it is "unreasonable, arbitrary or capricious," or if "the means selected" do not "have a real and substantial relation to the object sought to be attained." It should be apparent, without the argument's being labored, that words like "reasonable," "arbitrary," "capricious," and "substantial relation" are terms without fixed content. They are variables which mean different things to different people. What from one social point of view may be sweet reasonableness may from another be unreasonable and capricious. Nor does there exist a social calculus sufficiently exact to determine for all people what means have "substantial relation" to what objects.

Trying to guess, therefore, whether the courts will hold that the proposed land-use regulations for erosion control are within the police power is trying to guess whether Federal and State Supreme Court judges will believe that such land-use regulations are sufficiently necessary for the protection and promotion of the public health, safety, and welfare, that they are reasonable, not arbitrary or capricious, and bear a substantial relation to the goal of erosion control. There are two ways for divining the judicial mind—an appeal to precedent and an appeal to reason.

Among the regulations that the courts have in the past sustained, on the ground that each, in its own way, would promote the general welfare, have been: Prohibitions of the waste of gas and crude oil;

a requirement that owners of forest land remove brush and debris likely to cause fires; the required destruction of trees to prevent spread of cedar rust, San Jose scale, the yellows, citrus diseases, and apple scab; the required destruction of wheat crops because of the presence of corn borers on cornstalks in wheatfields; the required dipping or slaughter of diseased sheep and cattle; and regulation of livestock grazing within 300 feet of streams feeding a municipal water supply.

On the other hand, some of the regulations which have been held invalid as involving a deprivation of property or liberty without due process include: Prohibitions of the waste of natural gas, or of artesian well water; limitation of riparian water rights to those involving beneficial uses; prohibition of bathing by riparian owners in streams serving as sources of municipal water supply; limitations on diversion of surface waters; and limitations upon cotton production designed to maintain cotton prices.

The appeal to precedent reveals that in this case, as in the case of most legal questions, there exist competing analogies between which the courts are free to choose. But appeal may also be made to reason. Experience has adequately demonstrated that uncontrolled soil erosion causes silting of stream channels, reservoirs, and dams, loss of fertile soil material, overwash of rich lands by subsoil, silting of spawning beds, diminishing of underground water reserves, increase in speed and volume of rainfall run-off, and damage to highways, farm buildings, and other property in dust storms and floods. Erosion control is at one and the same time conservation of natural resources and food supply, wildlife preservation, flood control, water conservation. It would seem necessarily to follow that it is the direct promotion of the health, safety, and welfare of the people - hence "reasonable," "not arbitrary," within the police power, and not a deprivation of property or liberty without "due process." Whether the courts will so conclude it is too early to say.

Due Process and Public Purpose

Under the soil conservation districts laws the districts will have power to build terraces and check dams on private land, to contribute labor and materials to these operations, to lend or give the use of agricultural machinery and equipment as well as seeds and seedlings, and otherwise generally to assist private landowners to control erosion upon their lands. The purpose of this work is, of course, to make erosion control effective, but it cannot be denied that individual landowners will be receiving private benefit from such expenditure of the appropriations. The charge that these are expenditures of public funds for private rather than public purposes must be met.

The general rule seems to be that where the benefit to the individual is but incidental to the object of achieving a benefit to the general public, the expenditure will be held to be for a "public purpose." It is not easy, however, to predict whether the court will hold the private benefit to be merely incidental or to be the major object of the legislation in any particular case. Once again, to guess whether the courts will permit State appropriations to finance this type of work by the districts, appeal may be made to precedent and to reason.

Even more clearly than in the case of the police-power problem discussed above, the voice of precedent here blows both hot and cold. Expenditures for reclamation purposes involving loans to individual farmers have been held bad in some cases and valid in others. In the case of land-settlement programs where public funds have been appropriated to make loans to settlers, the benefit derived by the settlers has been considered merely incidental to the public welfare involved in opening up agricultural lands to cultivation. On the other hand, direct bounties to farmers and agricultural industries have been held unconstitutional as not for a public purpose. The courts have divided on the related question of whether loans to farmers to purchase seed and for other relief purposes in times of emergency are expenditures for a public purpose.[8] General expenditures for the benefit of agriculture have in a few cases been upheld on the specific ground that they tend to preserve farm lands from erosion. The courts originally divided sharply on the question of the constitutional propriety of using public funds for the drainage of lands for agricultural purposes. Today, however, there is very little tendency to deny the propriety of such appropriations. Similarly, the validity of expenditures for irrigation projects is established. In its recent decision sustaining the Alabama Unemployment Compensation Act, the United States Supreme Court said: "If the purpose is legitimate because public, it will not be defeated because the execution of it involves payments to individuals."

In this field, as in the field of the police power, there is considerable movement in the judicial decisions. Cases must be viewed, therefore, partly in the light of the year in which they were decided. Of this, more later.

On the side of the appeal to reason, it may be urged that it is difficult to escape the conviction that since the present appropriations have for their object the control and pevention of soil erosion to avoid the evil consequences summarized above, they advance a public purpose.

Delegation of Legislative Power

The general rule is simple; its application to the concrete instance is frequently difficult. The courts say that the legislature may not delegate to others the power to legislate. Inasmuch, however, as it is manifestly impossible for the legislature to anticipate every conceivable situation that will confront the administrative officers, and to define the rule to be applied to each situation, the general rule has come to be qualified somewhat as follows: The authority to prescribe administrative regulations to control application of the statute to particular instances, as well as the authority to determine their applicability in particular cases, may be delegated by the legislature to administrative officers, but the statute must contain specific "standards" to guide the administrative officers in formulating the regulations and determining their applicability.

The soil conservation districts law runs into this problem in several ways. It is necessary to decide whether a particular soil conserva-

[8] It should be remembered that the purposes for which State legislatures may make expenditures are here being discussed. The spending power of the Federal Government follows a somewhat different rule and is discussed later.

tion district shall be established; how the boundaries of the district shall be defined; whether a particular district shall be continued or its affairs wound up; whether land-use regulations shall be adopted; what the content of such regulations shall be; whether exceptions from the regulations shall be permitted; whether different regulations shall be made applicable to different lands. Each of these determinations must be admitted to be essentially legislative, yet it would be folly for the legislature to attempt to determine these questions in the statute for each district and each farm. Surveys must be made, technical facts accumulated and considered, public hearings held. The logic of the situation, therefore, compels the legislature to define the policy and to leave its effectuation to the executive branch of the Government.

It is a risky business to attempt to determine from the legion of decided cases just what "standards" the courts will deem sufficiently explicit to guide and control administrative discretion. Where the court deems the standard sufficient, the delegation of legislative power is said to be "proper." Where the court deems the standard insufficient, the provision is invalid for "improper delegation of legislative power." Where the court believes that the standard is one in name only, it may complain of "delegation run riot."

In the standard act, in determining where the boundaries of districts shall be laid, the State committee is directed to consider topography, soil composition, erosion distribution, prevailing land-use practices, relation of the proposed area to watersheds and agricultural regions, and other relevant physical, geographic, and economic factors. In determining whether particular districts shall be established, the committee is directed to consider these same factors and, in addition, the attitudes of the land operators within the defined boundaries, the votes cast in an advisory referendum on the question, the proportion of votes cast to the number of eligible voters, the wealth and income of the land operators, the probable expense of the proposed operations, and other relevant economic and social factors. These standards are supplemented by a statutory direction that the committee shall give due weight to the legislative determinations contained in the statute. These legislative determinations define the nature and causes of soil erosion, list the consequences of uncontrolled erosion, enumerate the appropriate corrective methods, and declare the policy of the State to conserve the soil. On the question of discontinuance of districts, the committee is directed to reconsider those factors that were originally required to be considered when the district was established, because circumstances may have changed since the original determination.

There is room for difference of opinion as to whether these standards are specific or general. Many cases have recognized, however, that legislatures cannot be asked to perform the impossible, and, hence, that where the legislature has been as specific as the nature of the circumstances will permit, the rule against improper delegation has been satisfied. The standards summarized above seem adequate in the light of the general run of the decisions.

Delegations of legislative power to administrative officers have been discussed thus far. There is a further aspect of the rule. The courts

have held that legislatures may not delegate their legislative power even to the people—who elect legislatures and make and amend constitutions. Therefore a State statute which is to be submitted to a general referendum of the people in the State and to go into effect only if approved by a majority vote in the referendum, is invalid, under the rule prevailing in all but a few States, as an improper delegation of legislative power to the people.

Since it is a rare rule of constitutional law that does not know its exception, there is an exception to this rule as well, known as the local option exception. A number of court decisions have held that the legislature may authorize a referendum in a particular locality less than the whole of the State, to determine whether a declared statutory policy or program shall be effective in that locality. The exception seems to have originated in the liquor option cases. In many States the courts have not had occasion to determine whether the local option exception will be recognized. In other States the cases are in considerable confusion so that it is very difficult to ascertain what the rule of the State may be. In the standard act it was desired to submit to a referendum of the farmers the questions whether a district shall be created and whether particular land-use regulations shall be adopted. This confusion in the decided cases, however, created a danger that these referenda would be held to be cases of improper delegation. This is the principal reason for the provision in the standard act that the referenda on these issues shall be merely advisory to the appropriate officers.

It has not been the principal purpose of this discussion to champion the constitutionality of the State soil conservation districts laws. Those laws have been used, rather, as an illustration of the way in which Federal and State constitutional provisions come to play upon a land program, prescribe to a large extent what its administrative provisions must be, and create the institutional environment within which it must be made to operate. The constitutional limitations discussed are applicable in greater or less degree to nearly every other State program dealing with the soil. From the same point of view, a Federal land program will now be considered. Because of its interesting recent judicial history, the adjustment program of the Agricultural Adjustment Administration is chosen for discussion.

THE AGRICULTURAL ADJUSTMENT PROGRAM

It is necessary to recall the essential characteristics of the agricultural adjustment program, so that the reader may understand how the constitutional and other legal issues arise. Under the original Agricultural Adjustment Act, approved May 12, 1933, the Secretary of Agriculture was authorized to enter into contracts with farmers under which the farmer, in return for a cash benefit payment, agreed to retire a stated percentage of his acreage from the production of particular commodities. The revenue for these payments was to be derived from the levy of taxes on the processing of the commodities involved.

Numerous processors brought suit to enjoin collection of the processing taxes, on the ground, among others, that the expenditure of the tax proceeds for payments to farmers under benefit contracts was

unconstitutional, because the purpose of the expenditure was to control the volume of agricultural production, and the power to effect such control has not been granted to Congress in the Constitution. The attempted exercise of a power not conferred, it was urged, violates the tenth amendment to the Federal Constitution which reserves to the States or to the people all power not conferred upon the Federal Government.

In defense of the constitutional validity of the program the Government contended that the challenged expenditure was a proper exercise of the general spending power conferred upon Congress. The Congress is given power in article I, section 8, clause 1 of the Federal Constitution "to lay and collect * * * excises to * * * provide for the * * * general welfare of the United States." The power to collect taxes for this purpose necessarily includes the power to spend the proceeds for the purpose. These expenditures do provide for the general welfare inasmuch as the benefit contract program is essential to the recovery of agriculture from the depression under which it has been operating since 1920 and, in turn, general national recovery from the depression is impeded by the depression in agriculture and may be expected largely to follow from recovery in agriculture. The program does not contravene the tenth amendment inasmuch as the Congress is exercising only a power expressly granted to it—the power to tax and spend.

The nub of the Government's argument may be stated thus: Even if it be assumed that the Congress is not given power in the Constitution to regulate the volume of agricultural production, by mandates which shall have the force of law and shall carry penalties for their nonobservance, it does not follow that the exercise of the spending power becomes invalid merely because its exercise may accomplish something of the same result that a regulatory statute might achieve. Where a given result may be accomplished in either of two ways (that is to say, in the present case, either by enforcing compliance with legal regulations or by purchasing voluntary compliance through payments given only to those who choose to comply) and the Constitution authorizes the Congress to use only one of those ways, the use of the authorized way does not become unconstitutional because the other way is not authorized.

It will be seen that the heart of the issue is: Just what are the limits of the "general spending power" of Congress?

The General Spending Power

It is a striking fact that in all our national history prior to the passage of the Agricultural Adjustment Act, the Supreme Court had in no case judicially determined the scope of the general spending power of Congress. Several times the question had been presented to the Court, but on each occasion the Court disposed of the case on other grounds. In this way, the Court permitted specific instances of the exercise of a presumed general spending power to continue, while leaving their constitutional validity undetermined. The Supreme Court's decision in *United States* v. *Butler*, 297 U. S. 1, (1936), which for the first time attempted to define the general spending power, is therefore one of the highest significance.

Since rhetoric, and even punctuation, have played a large part in the dispute over the meaning of clause 1 of section 8 of article I of the Constitution, it should be considered in full:

> Sec. 8. The Congress shall have power:
> To lay and collect taxes, duties, imposts, and excises, to pay the debts and provide for the common defense and general welfare of the United States; but all duties, imposts, and excises shall be uniform throughout the United States;
> To borrow money . . .;
> To regulate commerce . . .;
> To . . .; (Seventeen clauses follow the quoted first clause in section 8, each set forth as a new paragraph in this manner, and each beginning with the preposition "To".)

The first clause of section 8 is generally referred to as the general welfare clause. In this discussion it has been cited as the source of the "power to tax and spend" or the "general spending power."

Early in our history three views developed as to the proper interpretation to be given the general welfare clause. First, it was said by some that the clause should be construed as granting to Congress the power to promote the general welfare, i. e., the power to promote it in any way usually open to a legislature—by regulation, taxation, expenditure, or other means. This view has generally been rejected, on the ground that if adopted it confers upon the Congress the general power to promote the general welfare by any type of legislation, and would seem to make unnecessary the ensuing grant of a long list of specific powers. It would also deprive of significance the tenth amendment, reserving ungranted powers.

A second view has been that the general welfare clause is merely a limitation on the power to tax and spend, so that the proceeds of taxation may be spent only to pay debts, provide defense, or provide for the general welfare, but that the power to tax and spend is itself further limited by the subsequently enumerated powers. Under this view, the Congress may tax and spend to pay debts or to provide for the common defense or general welfare, only as a step in effectuating one or more of the other powers specifically granted, such as the power to carry on war, to regulate foreign and interstate commerce, to establish post offices and post roads, etc. The general welfare clause is thus read as though it were followed by the words "in the manner following, viz."

This view, known as the Madisonian theory, has often been objected to on the ground that it would deprive the clause conferring the power to tax and spend of all efficacy. There is nothing in the language of the Constitution to indicate that that power is intended to be merely an instrument of the other powers. A separate provision of the Constitution (the eighteenth clause of sec. 8) authorizes Congress to make all laws necessary and proper for carrying into effect the granted powers. The Madisonian interpretation of the general welfare clause would make of it an unnecessary duplication of the "necessary and proper" clause.

A third view, which expresses a middle ground between the other two, is commonly known as the Hamiltonian theory. This view maintains that the general welfare clause is a limitation on the power to tax and spend rather than an independent grant of legislative power, but that the power to tax and spend is independent of the subse-

quently enumerated powers. Hence, under this view, although the general welfare clause does not authorize Congress to promote the general welfare by direct regulatory measures, it does authorize the Congress to tax and spend in order to promote that welfare.

In the brief which the Government filed with the Supreme Court in defense of the agricultural adjustment program, the Government took the position that the third interpretation above summarized, the Hamiltonian theory, is the correct view of the general welfare clause. Conceding, therefore, that that clause [9] did not confer upon the Congress the power to control agricultural production by mandatory regulations, the Government maintained that the clause did confer upon the Congress the power to achieve such control of agricultural production as will result from so spending the proceeds of taxation as to induce farmers voluntarily to comply with agreed acreage reductions.

The Decision in United States *v.* Butler

On January 6, 1936, Mr. Justice Roberts delivered the opinion of the Court, holding that the processing tax-benefit contract program was unconstitutional because outside Federal power. In that opinion Chief Justice Hughes and Justices Van Devanter, McReynolds, Sutherland, and Butler concurred. Mr. Justice Stone delivered a dissenting opinion to the effect that the program was a constitutional exercise of the general spending power of Congress. Justices Brandeis and Cardozo concurred in the opinion of Mr. Justice Stone.

Mr. Justice Roberts' opinion stated the three interpretations of the general welfare clause as summarized above. Then, surprisingly enough in view of the result of the case, the opinion endorsed the Hamiltonian or middle-ground view, which was the interpretation of the clause urged upon the Court by the Government. This endorsement of the Hamiltonian theory is an endorsement with a difference, however, and the Court must be said to have added a fourth view to those that have so long battled for acceptance.

The confines of the power to tax and spend, says the majority opinion, "are set in the clause which confers it, and not in those of section 8 which bestow and define the legislative powers of the Congress." It follows that the general welfare clause, although it does not authorize Congress to promote the general welfare by regulatory measures, does authorize the Congress to tax and spend in order to promote the general welfare. But it follows further—and this is crucial—that the power to tax and spend is an independent coordinate power which may be exercised toward objectives other than those within the reach of the other powers conferred upon Congress in the Constitution. This conclusion is expressly drawn in the majority opinion, when it is said: "It results that the power of Congress to authorize expenditure of public moneys for public purposes is not limited by the direct grants of legislative power found in the Constitution."

Nor does the Court conclude that the expenditure will not promote the general welfare. The limitation is found elsewhere. The Court

[9] It should be noted that this concession does not answer the question whether such regulation may be achieved under one of the regulatory powers conferred upon Congress, such as the power to regulate interstate and foreign commerce.

says: "We are not now required to ascertain the scope of the phrase 'general welfare of the United States' or to determine whether an appropriation in aid of agriculture falls within it." And why is this true? Because "The Act invades the reserved rights of the States," which reservation is made by the tenth amendment.

That there is a remarkable internal inconsistency in this position of the Court may be more apparent if the Court's reasoning is paraphrased and its successive steps numbered:

1. The tenth amendment reserves to the States or to the people all, but only, those powers not granted to the United States;
2. One of the powers admittedly granted to the United States is the power to provide for the general welfare by spending money to that end;
3. This power is admittedly a broad power [10] and everything that falls within that power, being within the power of the United States, is not within the field of reserved powers;
4. The question which must be decided is whether the particular expenditures being made fall within the general spending power;
5. It is not, however, necessary to define the limits of the general spending power, because the present expenditures seek to control agricultural production and no power to achieve such control has been conferred upon Congress. The use of the spending power to achieve such control is hence forbidden by the tenth amendment.

With the statements numbered 1 to 4, inclusive, there is no quarrel. The fifth statement, however, converts the discussion into argument in a circle. If the limits of the general spending power are not defined how can it be concluded that the expenditure under review falls outside those limits? And it is only if the expenditure does fall outside those limits that it can violate the tenth amendment. It will not do to point to the fact that no express power to control agricultural production has been conferred upon Congress. For such an argument would assume that the spending power may not be exercised except to advance some other governmental power expressly conferred upon Congress. This the Court has itself denied in the language quoted a few paragraphs above.

The opinion of the majority of the Court is, thus, subject to a serious internal inconsistency—but this is true only so long as we assume with the Court that it is endorsing the Hamiltonian view of the general welfare clause. For in fact the majority opinion is doing something else. Acceptance of the Hamiltonian view would pose for the Court the single question whether the particular expenditure authorized in the Agricultural Adjustment Act will or will not promote the general welfare. That question the Court refused to answer. Rather, the Court has read the tenth amendment as though it contained a qualification upon the power to tax and spend which is admittedly granted to Congress.

Mr. Justice Stone in his dissenting opinion has stated this most succinctly. The majority of the Court is, he says, in effect announcing:

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[10] Mr. Justice Roberts said, in part: "How great is the extent of that range (the range of legislative discretion) when the subject is the promotion of the general welfare of the United States, we need hardly remark."

Let the expenditure be to promote the general welfare, still, if it is needful in order to insure its use for the intended purpose to influence any action which Congress cannot command because within the sphere of State government, the expenditure is unconstitutional.

This use of the tenth amendment as a limitation upon the powers granted to Congress is not dictated by the terms of that amendment. The amendment reads: "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States, respectively, or to the people." The subject of this sentence is "The powers not delegated * * * nor prohibited." A reservation of powers not granted does not express a limitation upon powers that are granted.

Whether the logic of the majority opinion is found tenable or otherwise, that opinion, together with the opinion in the Social Security Act case, discussed later is today the only authoritative interpretation of the general spending power, and will stand until modified or overruled by the Court, or superseded by constitutional amendment.

But there is internal evidence in the majority opinion that the Court shrank from the consequences of its own conclusion. It therefore drew back—not alone by stating that it was approving the Hamiltonian view, but also by distinguishing between various types of exercise of the spending power. Some types of exercise of the spending power, it says in effect, may be valid, even though they involve expenditures upon objects possibly not attainable under the other legislative powers. Light as to the permissible expenditures must therefore be sought further in the opinion.

The majority opinion says:

We are not here concerned with a conditional appropriation of money, nor with a provision that if certain conditions are not complied with the appropriation shall no longer be available. By the Agricultural Adjustment Act the amount of the tax is appropriated to be expended only in payment under contracts whereby the parties bind themselves to regulation by the Federal Government. There is an obvious difference between a statute stating the conditions upon which money shall be expended and one effective only upon assumption of a contractual obligation to submit to a regulation which otherwise could not be enforced.

There is other language in the opinion from which it might be argued that the Court is prepared to conclude that while the tenth amendment prevents the use of the spending power for payments to farmers in this manner, such payments may validly be made to States on the condition that the States in turn disburse the funds to farmers in return for appropriate undertakings by the farmers. This, however, raises the question as to the types of conditions which the Federal Government may impose upon State acceptance of payments without violating the tenth amendment.

Still further, there are references in the opinion to agriculture as being a local matter. At one point Mr. Justice Roberts said that agricultural production is "a purely local activity." At another point he said:

It does not help to declare that local conditions throughout the Nation have created a situation of national concern; for this is but to say that whenever there is a wide-spread similarity of local conditions, Congress may ignore constitutional limitations upon its own powers and usurp those reserved to the States.

Does this mean that agriculture is inherently a local activity, that the general welfare is not involved in its well-being, and therefore that the tenth amendment has placed agriculture entirely outside the scope of legitimate Federal concern or activity?

The Supreme Court's first essay at a definition of the general spending power has thus created no little uncertainty. Clarification must be awaited in future opinions, unless the language of the Constitution be amended in the meantime.

But the Federal concern for the problems of agriculture did not cease on January 6, 1936. Hard upon the heels of the Court's decision, therefore, Congress enacted the Soil Conservation and Domestic Allotment Act of 1936. And, on February 16, 1938, the President approved the Agricultural Adjustment Act of 1938.

THE AGRICULTURAL CONSERVATION PROGRAM

In the act of 1936, approved just 54 days after invalidation of the processing tax-benefit payment program, an attempt was made to avoid the characteristics of the original program which the Supreme Court had condemned in *United States* v. *Butler*.

The Court's decision in the Butler case had illegitimated production control as a Federal objective. The net distinction between the original adjustment programs and the conservation programs under the Soil Conservation and Domestic Allotment Act might therefore possibly be summarized as follows: In the original programs production control was the central objective, with soil conservation and good farm management as incidental benefits which were sought to be achieved as far as possible. In the agricultural conservation programs soil conservation and good farm management were the central objectives, while a limited amount of production control not infrequently developed as a natural byproduct. Such indirect production control would normally result insofar as the crops for which production-control programs had earlier been instituted were, in fact, found to be erosion-producing and soil-depleting crops.

The new act declared it to be the policy of Congress to preserve soil fertility and to diminish improper and promote proper land uses. To this end the Secretary was authorized to make payments or grants of other aid to agricultural producers, such payments to be measured by their adoption of land-use practices designed to achieve soil restoration, soil conservation, and the control of erosion. It was expressly provided that the Secretary shall not have power to enter into any contract binding upon any producer.

Thus, the attempt to purchase voluntary farmer compliance with agreed acreage reductions in the interest of control of the volume of agricultural production was abandoned. Further, in lieu of the execution of written contracts, the Secretary of Agriculture offered to make payments to those producers who complied with preannounced conditions. Still further, the program was to be financed by a direct appropriation out of the Treasury rather than by the levying of processing taxes. The attempt to comply with the language of the majority opinion in *United States* v. *Butler* is obvious. Since no judicial decisions have been rendered upon the constitutionality of this program, there is no light on the question whether this interpretation

of the permissible scope of the spending power will meet judicial sanction.

THE AGRICULTURAL ADJUSTMENT ACT OF 1938

The incidental amount of production control achievable under the agricultural conservation programs did not serve to prevent the reaccumulation of surpluses and the threat of even greater accumulations.

The present act provides for continuation of the agricultural conservation program. In addition, under designated conditions, loans are to be made on agricultural commodities to producers who are cooperating in the conservation programs (and, under certain conditions and limitations, to noncooperators), in order to build up reserves or an "ever-normal granary" of particular commodities. When the reserves reach stated levels, marketing allotments may, under certain conditions, be established in the interest of controlling the total volume of particular agricultural commodities to reach the markets of the Nation. Other provisions of the act, among them crop insurance for wheat, are not considered here.

It is important to distinguish the first two steps in this new program—the making of cash payments to farmers in return for conservation practices and the extension of loans on agricultural commodities—from the third step, which is the assignment of marketing quotas. The first two depend for their constitutional validity chiefly upon the power to tax and spend. The third depends upon the power to regulate interstate and foreign commerce.

It is not intended here to undertake any extended analysis of the relevant arguments on these constitutional issues. Our concern is merely to understand the immediate relevance of the decision in *United States* v. *Butler*. It will be apparent that the program of making payments to farmers in return for their following designated conservation practices and extending commodity loans to the cooperating farmers is an exercise of the power to tax and spend not obviously dissimilar from the program condemned in *United States* v. *Butler*. The majority opinion in the Butler case emphasized that the power to control agricultural production has not been expressly conferred upon Congress.

The new act proposes to go further than the original program. Where the original program sought to purchase compliance with agreed acreage reductions, the new program proposes, under certain conditions, to regulate marketing and to assess penalties upon nonconformers. The new act relies for this regulatory feature, however, not upon the power to tax and spend, but upon the power to regulate commerce among the several States and with foreign nations. The scope of the commerce power was not in issue in the Butler case.[11] Whether the implications of the decision in that case cast doubt upon the validity of the proposed program under the commerce power is a debatable question.

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[11] The majority opinion said in part: "Despite a reference in its first section to a burden upon, and an obstruction of the normal currents of commerce, the act under review does not purport to regulate transactions in interstate or foreign commerce. * * * Indeed, the Government does not attempt to uphold the validity of the act on the basis of the commerce clause, which, for the purpose of the present case, may be put aside as irrelevant."

Since the decision in the Butler case, however, some very significant trends in constitutional interpretation have appeared. The decisions of the Supreme Court, in May 1937, in the cases sustaining the constitutionality of the Social Security Act have affirmed the existence in the Congress of a broad power to appropriate the proceeds of taxation for all purposes which will aid the general welfare. In turn, the decisions sustaining the validity of the National Labor Relations Act have revived the broad sweep of the power to regulate interstate and foreign commerce which the great Chief Justice, John Marshall, originally affirmed in *Gibbons* v. *Ogden*, as long ago as 1824.

It may be noted in passing, also, that there has been a slight change in the personnel of the Supreme Court. The vote on the original adjustment program was six to three. Justices Van Devanter and Sutherland, who were two of the six, have since retired. It is at least conceivable that Justices Black and Reed, the latest appointees to the Court, would, on the original question, have voted with the minority rather than with the majority. It is still open to the three dissenting judges to reaffirm in future cases the position stated in their dissent. It is therefore possible that even the original adjustment program, as well as the present program, insofar as they deal with the exercise of the power to tax and spend, will be supported by five of the nine Justices. At least two of the remaining four have, in the Social Security Act and National Labor Relations Act cases, reversed [12] positions formerly taken by them. It is again possible that one or both of these members of the Court may feel that the decision in the Butler case should not stand in the way of the new legislation. The importance of Court personnel in the adjudication of constitutional issues is a point to which further reference will be made.

In the case of State programs dealing with the soil the most crucial issues are those that revolve around the concepts "due process," "police power," "public purpose," "equal protection of the laws," and "delegation of legislative power." In the case of Federal legislation in this field the central question must always be the existence of Federal power to deal with the matter at all. Only when this central question has been answered in favor of Federal power can we arrive at such other issues as delegation of legislative power, due process, and the like. These other issues are not dissimilar when applied to Federal legislation from the form they take in the case of State programs. Because so large a part of the financing of soil programs is being carried by the Federal Government it has seemed appropriate to devote so much space to a consideration of the scope of the Federal spending power.

PRESENT TRENDS AND NEEDS

In this final section the threads will be drawn together. What changes are needed in the various sets of legal rules, or perhaps in our legal institutions, to enable the establishment and effective operation of the economic and governmental relations required for proper land

[12] This is a matter of personal judgment. In the Court's opinions in the Social Security and Labor Relations Acts cases, the earlier decisions in the Agricultural Adjustment and Bituminous Coal Acts cases were not overruled, but "distinguished."

use? What are the present trends in judicial decisions, and will those trends raise or lower the legal barriers to the effective operation of those economic relations?

The Judge and the Constitution

The careful reader of the foregoing discussion will have seen that there is an enormous field for free and independent exercise of discretion by judges in deciding constitutional and other legal issues. He will have seen that the act of judicial decision is an act of choice among competing analogies presented by competing precedents. He will have seen, also, that the language of constitutions presents nearly limitless opportunity for varying interpretations.

There are some provisions in constitutions and in statutes which are sufficiently specific to enable reasonable men to agree readily on their meaning. Thus, the Federal Constitution provides that "The Congress shall assemble at least once in every year," and that "The Senate shall have the sole power to try all impeachments." Provisions such as these are reasonably fixed and certain in content. A court in giving effect to them is letting the Constitution speak. But the important provisions of constitutions can almost never be couched in terms equally specific and unmistakable. Consider such provisions as: "The Congress shall have power: To lay and collect taxes * * * to * * * provide for the * * * general welfare of the United States"; "To regulate commerce * * * among the several States"; "The citizens of each State shall be entitled to all privileges and immunities of citizens in the several States"; "Congress shall make no law * * * abridging the freedom of speech, or of the press"; no State shall "deprive any person of life, liberty or property without due process of law; nor deny to any person within its jurisdiction the equal protection of the laws."

As has been shown in the foregoing discussion, terms like "due process of law," "reasonable," "arbitrary," "real and substantial relation to the object sought to be attained," "capricious," "public purpose," "general welfare," "equal protection of the laws," "delegation of legislative power," "commerce among the several States," are variables which mean different things to different people. In the last analysis these basic constitutional provisions mean what the judges who are deciding particular cases think they ought to mean, and hence say they mean.

Edward S. Corwin, in his book, The Twilight of the Supreme Court, subtitled A History of Our Constitutional Theory, (*76a*) in discussing particularly interpretation of the Federal Constitution by the United States Supreme Court, has stated this point succinctly. He says:

> * * * The Court, as heir to the accumulated doctrines of its predecessors, now finds itself in possession of such a variety of instruments of constitutional exegesis that it is able to achieve almost any result in the field of constitutional interpretation which it considers desirable, and that without flagrant departure from judicial good form. Indeed, it is altogether apparent that the Court was in actual possession and in active exercise of this "sovereign prerogative of choice" some years before most of the Justices were intellectually aware of it, albeit the present Chief Justice was not among the unsophisticates. Even prior to his first appointment to the Supreme Bench, as the successor of Justice Brewer, Mr. Hughes had spoken the notable words quoted at the outset of this volume: "*We*

are under a Constitution, but the Constitution is what the judges say it is." Horribly as it must have grated upon the ears of Mr. Hughes's predecessor, this incisive statement describes with accuracy not only an achieved result but a still operative process as well. (Dr. Corwin's italics.)

Dr. Corwin has said, further, that interpretation of the Constitution by the Supreme Court falls into "three tolerably distinguishable periods." The first reaches to the death of John Marshall, and is said to be the period of the dominance of the constitutional document. "The tradition concerning the original establishment of the Constitution was still fresh" and the theories of the framers of the Constitution, readily available in The Federalist, were much relied upon by the Court. The second period is said to stretch from the accession of Chief Justice Taney in 1835 to the death of Justice Brewer in 1910. Dr. Corwin calls this the period of constitutional theory, during which the text of the Constitution tended to fade into the background and The Federalist ceased to be cited.

Among the theories which in one way or other received the court's sanctifying accolade during this period were the notion of Dual Federalism, the doctrine of the Police Power, the taboo on delegated legislative power, the derived doctrine of Due Process of Law, the conception of liberty as Freedom of Contract, and still others.

The third period is said to be the present and is referred to as that of "Judicial Review pure and simple," under which the Court's legislative discretion is exercised in the form of a review of the constitutionality of acts of Congress and of the State legislatures.

Perhaps it should be emphasized that the very nature of a constitution makes it imperative that its provisions shall be couched in broad general phrases. A constitution is built to endure over a reasonably extended period of time. It must seek, therefore, to lay down general principles, leaving to each generation the nice adjustment of the principles to the varying problems with which each must deal. But if each generation must interpret and apply, then the constitution is at the mercy of its interpreters.

With this knowledge of where the "ultimate power" lies, some present trends and present needs may be briefly considered.

Present Trends and Needs

A consideration of land programs lends weight to the widespread conviction that there has developed an historical necessity for an extension of Federal functions and of the corresponding Federal constitutional power.

There is need for the Federal Government to have the power to spend the proceeds of national taxation in such manner as the Congress believes will promote the general welfare. That power, it seems clear, should carry with it the power to impose such conditions upon the acceptance and expenditure of the money by States, public agencies, or individuals as are reasonably calculated to realize the purposes for which the expenditure is made. The majority opinion of the Supreme Court in *United States* v. *Butler,* which invalidated the original agricultural adjustment program, while affirming the existence of this power, attempted to surround it with nearly fatal restrictions. More recent decisions of the Supreme Court, in particular the decision in

Helvering v. *Davis*, in which Mr. Justice Cardozo delivered the opinion of the Court on May 24, 1937, sustaining the validity of the old-age benefit provisions of the Social Security Act, give ground for hope that the decision in *United States* v. *Butler* will be gradually circumscribed and perhaps in time overruled, and that a broad scope for the Federal spending power will be established by the Court. That result may be achieved by denying to taxpayers the opportunity to challenge Federal appropriations, as in the recent cases involving loans to counties and municipalities for constructing electricity-distribution systems, or by affirming the broad scope of the power, as in *Helvering* v. *Davis*. Both trends are in evidence.

In addition to a general spending power, effective administration of land-use programs will require the exercise of a broad Federal regulatory power over "commerce among the several States." Here, again, the recent decisions invalidating the Railroad Pension Act, the National Industrial Recovery Act, and the labor provisions of the Bituminous Coal Conservation Act speak a different language from that spoken in the still more recent decisions sustaining the National Labor Relations Act. These shifts and trends in recent judicial decisions are themselves eloquent testimony to the central role played by independent judical discretion in the decision of constitutional issues.

Is there need for a constitutional amendment conferring upon Congress power to control floods and soil erosion, or perhaps the general power to conserve natural resources? The answer to this question will in large part depend upon the scope which the judicial decisions of the next few years will lend to the spending and commerce-regulating powers of Congress. A broad scope for those powers may be sufficient to enable such Federal action in this field as is desired. It will depend, further, on the effectiveness of the newly instituted State programs in this field. If the States fail to provide for the needed land-use regulation for erosion control and flood control, if interstate soil and water conservation districts prove necessary, if State action fails to control destructive logging and other practices in private forests, to cite three instances out of many, the suggested amendment would permit such supplementary Federal action as might be considered desirable.

On the side of governmental action by the States, the most imperative needs are for a broader judicial definition of the scope of State police power, and of the "public purposes" for which the proceeds of State taxation may be spent. State regulatory legislation under the police power must run the gamut, not only of the respective State supreme courts, but also of the United States Supreme Court. If the recent decision of the United States Supreme Court in *Nebbia* v. *United States*, sustaining the validity of the New York milk price regulatory statute, is adhered to and followed, the police power of the States should be found adequately broad for the needs of regulation. (The decision has been quoted in discussing the police power.) That decision gives a broader scope to the police power than has been granted by many of the State supreme courts.

It should be noted that if a State supreme court holds invalid a State regulatory statute on the ground that it violates the due process

provision of the State constitution, that decision is not reviewable by the United States Supreme Court. For this reason, a State supreme court may enforce for State legislation a narrower version of the police power than the United States Supreme Court is prepared to enforce under the fourteenth amendment to the Federal Constitution. The States differ widely in the scope which their respective supreme courts today give to the police power.

The United States Supreme Court has held that a Federal taxpayer has no standing in court to challenge the validity of a Federal appropriation, on the theory that a taxpayer's contribution to the Federal revenues, and hence his "interest" in the manner of their expenditure, is so small that he sustains no "direct injury" from the expenditure. Under some circumstances—as in the case of *United States* v. *Butler*, where the court found a distinction between such a case and a case where a tax is levied and an appropriation made as steps in a single program—a taxpayer is permitted to challenge an appropriation. In nearly all of the States, however, the State courts have held that a State taxpayer has standing in court to challenge the validity of any State appropriation. State appropriations are valid only if for a public purpose, as mentioned above. This discussion of the public purpose issue has indicated, however, that there is a slow trend toward liberalizing the scope of the purposes which the courts will recognize as public.

There is need, further, of a practical definition of what constitutes "improper delegation of legislative power." Until recently, in the case of Federal action the Supreme Court had asserted the existence of a prohibition against improper delegation, but had sustained every challenged instance of delegation. Constitutional theorists had practically come to the view that the Supreme Court was prepared to announce that all delegations of legislative power were beyond judicial review—were, perhaps, to be labeled as political rather than justiciable questions.[13] It was felt, in other words, that the rule against delegation was about to become a dead letter. In 1934, for the first time in our history, the Supreme Court in the so-called hot-oil case gave effect to the delegation rule, and held invalid a congressional statute authorizing the President, under certain circumstances, to prohibit the shipment in interstate commerce of oil produced in violation of State law. Other instances of delegation of legislative power have since been held invalid. Today, therefore, the rule against improper delegation exists in the case of Federal action as well as in the case of State action.

The Federal rule tends still, however, to be more liberal than the corresponding State rules, although the States differ widely in this respect. On this problem, as on all problems of statutory and constitutional interpretation, careful draftsmanship will help a great deal. There are limits, however, to the capacity of draftsmanship to be of help. It is necessary that the courts shall apply realistically the rule which they themselves assert—that where the legislature has been as specific in formulating the standard to guide administrative discretion as the circumstances will allow, the administrator may be authorized

[13] The Court, for example, has held that the constitutional direction in art. IV, sec. 4, that "The United States shall guarantee to every State in the Union a republican form of government," presents a political question not justiciable in any court.

to fill in details and prescribe subordinate regulations. A realistic sense of the need for administrative flexibility is possessed by many judges and needed by the rest.

Do the Constitutions Need Amendment?

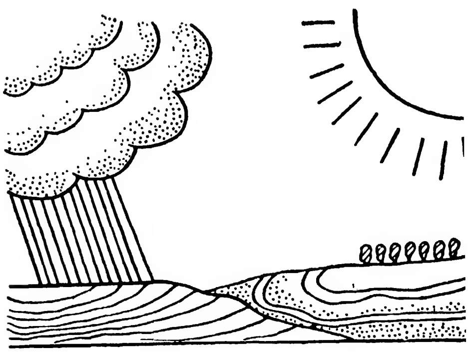
It will be apparent that many of the difficulties here indicated may be solved by the judges themselves, in the trends of their constitutional interpretation. It is open to the people, by constitutional amendment, if the judges fail them, to revise their constitutions and thus, to some extent, to reverse the trends of judicial decision. But it should never be forgotten that the amendments themselves will be interpreted by the judges.[14]

It is customary in discussions of this subject to conclude with a ringing cry for an enlightened and public-spirited legal profession. And the need for judges and lawyers informed as to social processes and sensitive to the needs of a dynamic social and economic order is inescapable. The conclusion should not be drawn, however, that no other effort need be made than to revise the training received by lawyers and judges. We shall all of us be always in need of more education. Every school of thought numbers among its adherents, however, the learned as well as the uninformed. The acts of lawyers and judges spring less from ignorance than from the dominant philosophy of life of the individual. Reactionary judicial decisions may seem to some unduly restrictive, but they do no more than restrict action which, in the minds of others with different views, ought to be restricted. Each individual seeks to influence the course of events, in view of his own hopes and fears.

What the land-use planner should here make note of, therefore, is the actual distribution of governmental power which prevails in the field of land use. This distribution includes not only a division between national and State functions, but also one between legislature, executive, and judiciary. The social scientist seeking to illuminate and guide social activity neglects at his peril to discern correctly the forces which do in fact control events. It is those forces he must learn to guide or control.

[14] When Walton Hale Hamilton was asked recently how he would phrase an amendment to confer upon Congress the power denied it by the Court in the N. R. A., Railroad Pension, and Bituminous Coal cases, he suggested the "power to regulate commerce among the several States."

The Farmer and the Soil



ULTIMATELY, the conservation and wise use of our soils depends on the individual farmer. This part of the Yearbook, comprising the longest single section, deals with soil management and practices, with a view to increasing the individual's understanding of possible ways to solve his own problems.

Beginning with tillage and tillage implements, the authors next take up deficiencies of the soil in organic matter, nitrogen, phosphorus, and potassium, and tell in general how these deficiencies may be corrected.

Next they consider the purpose and use of rotations, cover crops, farm manures, and other organic amendments in the farming system.

Following this there are several articles on fertilization and liming. These give an account of modern methods of determining fertilizer needs, describe the numerous separate fertilizer materials on the market, deal at some length with mixed fertilizers, give the newer discoveries on the most effective ways to place fertilizers, and finally consider the fundamentals of soil acidity and liming.

Next there is a group of articles on erosion control, dealing first with the nature and importance of erosion, then with remedies and prevention—the effective use of forests and grass, strip cropping, and mechanical measures such as terracing and contour furrowing. More important than any single measure is the right combination of several of them, and this is dealt with in a separate article.

The special problems of dry-land farming are considered next, followed by articles on irrigation, on drainage in humid and arid regions, and on the management of forest soils.

WHAT *are the three primary purposes of tillage? What determines the time when tillage operations should be carried on in various regions? How much tillage should be given, and is it better to have a fine or a coarse surface? What is the effect of tillage on the supply of nitrogen, on plant diseases, and on insects? What is its place in erosion control? Such questions are considered in this article.*

Tillage

By JOHN S. COLE *and* O. R. MATHEWS [1]

"THEREFORE Jehovah God sent him forth from the garden of Eden to till the ground from which he was taken." The man with the hoe is pictured by the artist and sung by the poet as fulfilling in toil the curse upon the ground. Yet the tiller of the soil by his every act evidences faith in the futher promise that there shall be a seedtime and a harvest. He knows that upon his skill depends the abundance of the harvest, and he has contrived to lift the burden of toil by utilizing the intelligence with which he was endowed by his Creator.

The first practice of the art of soil tillage marks the beginning of civilization. In its most primitive form, the primary object of tillage was to subdue or destroy the native vegetation in order that the desired plants might develop free from its competition. To destroy competing vegetation is still one of the primary objects of tillage in its most highly developed form.

The first tools were crude chopping or digging implements of wood, stone, shell, or bone, depending on the material available. The area that could be tilled was sharply limited. The second stage of tillage came with the application of the power of domesticated animals to the task. It was now possible to substitute a steady forward movement of the tillage implement for the successive chopping or spading motions of the hand implements. The crooked-stick plow to stir the soil and the brush drag to smooth and fine the surface, to kill small weeds, and to cover the seed became standard implements, and their use greatly extended the ability of man to produce a sufficient food supply.

In the further development of tillage practices, the fundamental purposes and methods have remained unchanged, but efficiency has

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increased through the development of implements.[2] The spring-shanked field cultivator is the modern steel prototype of the crooked-stick plow of the ancients. The development of steel has made possible the sharp cutting edges and the curved and polished surfaces with which all soils may be cut, stirred, or turned in any way that may be desired. The straight-line movement of the plow and drag has been supplemented with the rotary movement of such implements as the disk and the rotary hoe. Finally there has come the substitution of mobile mechanical power for animal power. This, with modern machinery for tilling the soil and harvesting the crops, has so multiplied the power of man to subjugate the soil to his needs for the necessities of life as to release untold energies for other activities.

PURPOSES OF TILLAGE

Three primary objectives dependent on time and place may be recognized as the fundamental purposes of tillage: (1) To prepare a suitable seedbed; (2) to eliminate competing weed growth; and (3) to improve the physical condition of the soil.

Under preparation of a seedbed may be grouped a wide range of tillage operations performed during the period before seeding, some of which may seem foreign to seedbed preparation. Among these may be cited operations the immediate objective of which may be the improvement of the physical condition of the soil, the creation of a condition favorable to the elaboration of plant food, or the destruction of a crop of weeds, but the ultimate object of which is to create a seedbed physically, chemically, and biologically fitted to the growth of crops.

The preparation of a seedbed may involve the destruction of the native vegetation, the destruction of sod or another crop in a rotation, or the destruction of weeds or other unwanted vegetation. It may on the other hand involve only removing, burying, or incorporating in the soil the dead or unharvested residues of a crop. Where none of these problems is present, it may be concerned solely with changing the condition of the surface, to loosen and mellow or to compact it. A seedbed generally should be fine, compact, and free of trash or growing vegetation, but in areas subject to wind erosion safety may require leaving clods and crop residues on the surface. A seedbed should contain moisture to germinate the seed and to support the growth of the resulting plants. In semiarid sections tillage in preparing a seedbed is purposely directed to the conservation of water and its storage in the soil, but in humid sections this is a less important consideration.

Tillage to eliminate competing weed growth has the primary purpose of preventing the competition of weeds or other unwanted plants for water, plant food, and sunlight, but it may have numerous other objectives that will be considered later. Crops that are planted in rows or hills or as individual plants are so universally cultivated while they are growing that they are classed as intertilled crops. Small grains, grasses, and some legumes occupy all the ground and are seldom tilled after seeding, although there are exceptions. Alfalfa

[2] For more complete descriptions of tillage implements, many of them illustrated by photographs, see the article, Tillage Machinery, p. 329.

fields are often cultivated in the early spring to destroy winter annuals the growth of which would cause more injury to the alfalfa than is caused by the tillage implement.

Tillage to improve the physical condition of the soil where a crop is growing cannot be separated from tillage to destroy weeds, as both purposes are generally attained by the same operation. Cultivation to attain one of these primary objectives can almost always be performed with an implement that will also attain the other.

Tillage to prepare a seedbed or to care for crops while they are growing may also be directed to the protection of the soil against erosion by wind or water, or the soil may be tilled specifically for this purpose.

CHARACTER AND KIND OF TILLAGE OPERATIONS

There is no one character by which tillage operations may be satisfactorily classified, but the one most generally recognized is that of depth. The plow is the type implement of deep tillage. Depending on its form and the condition of the soil, it may invert a furrow slice with little other disturbance, stand it on edge, or pulverize it. The soil may be loosened to greater depths by a subsoiler run in the bottom of the furrow either as an attachment to the plow or as a separate implement. An implement descriptively known as a chisel is designed to loosen the soil to depths of as much as 30 inches without inversion or complete disturbance of the surface. Tillage below the ordinary depths is designed to break up hardpans or other intractable subsoils and to provide channels for the ready penetration of water. The lister and bedding plows are modifications of the plow to accomplish specific purposes or to meet special conditions.

Shallow or surface cultivation is accomplished by disks, shovels, spikes, or cutting and scraping blades. Such cultivation is employed to prepare a seedbed after the land has been plowed, or sometimes without plowing, and is almost exclusively the type of cultivation practiced in the intertillage of growing crops.

TIME OF TILLAGE

The time of tillage is controlled by the seasons, open or frozen, wet or dry; by the crops that are grown; by the growth habits of the vegetation that the tillage is intended to kill or suppress; and by the insects it is intended to control. Where these permit a choice, experience in any section may soon indicate the alternative that should be selected to produce the best results. Where the results following tillage at different times are equally good, the availability of labor or the desirability of making the best distribution of it may be the deciding factor.

The stiffer and more resistant the soil, the greater should be the care and attention given to bringing it into perfect tilth before it receives the seeds or plants. Cultivation when too wet may injure the structure of a heavy soil by puddling it so that intractable lumps and clods are formed when it dries. Cultivation when it is too dry may break it into lumps that are difficult to reduce to a desirable tilth.

Conversely, the more sandy and lighter the soil the smaller is the

opportunity of improving its structure by proper tillage and the less the likelihood of damaging it by improper tillage.

In humid sections where there is danger of water erosion or loss of fertility by leaching, tillage should be timed so as to keep the ground covered with vegetation during the rainy period or the dormant season. In subhumid or arid sections, tillage that leaves the soil bare during the rainy season contributes to the storage in the soil of water essential to production. At Hays, Kans., it has been shown that where winter wheat is grown following winter wheat the yields obtained by beginning cultivation immediately after harvest may be as much as 50 percent greater than where cultivation is delayed until near seeding time. Under conditions there, the more completely the 90 days between harvest and seeding is made a tillage period, the higher are the yields. Farther west in the State where the rainfall during this period is not heavy enough to provide for storage in the soil, the benefits of early tillage are greatly reduced or nonexistent. In western North Dakota and in the dry-farming section of Montana, a delay of 1 month in the time of beginning the tillage of summer-fallowed land reduces the yield of wheat grown on it 6 bushels to the acre. At Moro, Oreg., a similar reduction resulted from delaying the time of plowing fallow land.

In some parts of the spring wheat area, where land plowed in the spring may produce more than that plowed in the fall if both are seeded at the same time, it is considered desirable to have a large acreage plowed in the fall in order to realize the advantages of early seeding that it permits. Still farther north the soil freezes so soon after harvest that there is little opportunity for plowing in the fall. This contributes to the use of summer fallow, with which most of the necessary tillage in preparation for the next crop can be done while the current crop is growing.

AMOUNT OF TILLAGE

Tillage may loosen the soil and make its surface coarse and more cloddy, or it may compact the soil and make its surface finer. The effect depends on the amount as well as the kind of tillage. The first tillage of a compact soil loosens it. If the soil is wet this aerates and warms it. If the soil is dry it puts the surface in condition to resist run-off and facilitates the penetration of water.

The first tillage operations are generally of necessity with the deeper running, heavy-draft implements. Successive cultivations with lighter draft implements to prepare a seedbed or to prevent the growth of weeds, compact the soil, and smooth and fine the surface. Up to a certain point this is necessary and desirable, but beyond that point it is destructive of its purposes and may be detrimental.

A smooth, fine surface in the heavier soils is likely to be puddled with the first impact of rain, and instead of penetration of water into the soil, there is run-off of water and the loss of soil by erosion. In semiarid sections such a surface invites soil blowing and erosion by wind. A coarse, granular surface facilitates the penetration of water and resists erosion by wind and water.

The amount of intertillage to be given most crops is determined by necessity, which may in turn be determined by the character of the

season. In some years one or two cultivations may keep a corn crop free from weeds, whereas in other years three or more cultivations may be required. Tillage of growing crops is now regarded primarily as a means of weed control, as it is becoming better recognized that the chief purpose of cultivation is to destroy weeds, not to create a mulch. Tillage sufficient to control weeds is usually all that is necessary. Under special conditions, tillage may be desirable to dry out a water-logged soil or to roughen a soil that has become too smooth or too compact, but even under these conditions implements that destroy weeds while accomplishing the primary purpose are utilized.

The selection of implements may also govern the amount of tillage necessary. The popularity of the rod weeder in the intermountain region is due largely to the fact that it destroys all the weeds so that fewer cultivations are necessary. The trend in cultural implements towards those that do a more thorough job of weed killing is evidenced by the increased use of overlapping sweeps on tillage implements.

EFFECT OF TILLAGE ON NITRIFICATION

The growth of crops is dependent on a supply of nitrogen, chiefly in the form of nitrates, which are developed in the soil by bacteria. Heat, moisture, and oxygen are essential to bacterial activity. Tillage tends to create favorable conditions and in some cases is practiced primarily for this purpose. A yellow and unthrifty appearance of a crop such as corn in a cold and waterlogged soil may sometimes be corrected by cultivation that loosens and aerates the surface soil and makes conditions favorable for nitrification.

The advantage of early preparation of a seedbed for a crop such as winter wheat may lie largely in the opportunity for accumulation of a store of nitrates. This is a highly important consideration where the nitrogen content of the soil is low. In the Columbia River Basin, where the period between harvest and seeding is one of drought, one of the advantages of summer fallow is that it provides a moist soil at the season when temperatures are favorable to nitrification.

Cultivation to destroy weeds or prevent their growth and to conserve moisture provides conditions that are also the most favorable for nitrification.

In humid areas tillage of the right type is essential to the best use of nitrates accumulated by cover crops, particularly leguminous cover crops. This is not primarily a matter of nitrification, but rather of utilization of nitrates without waste. Tillage that incorporates the crop with the surface soil long enough in advance of seeding for decomposition to set in, but not long enough for the nitrates to be dissipated, is essential to this purpose.

EFFECT OF TILLAGE ON PLANT-DISEASE CONTROL

Tillage is an important factor in the control of plant diseases or in avoiding damage by them. Generally tillage that provides conditions favorable to a vigorous growth helps crop plants to escape damage by diseases. Tillage may be a direct measure of control by preventing the growth or scattering of the organisms that cause the disease. This is well illustrated by scab of wheat, barley, rye, and oats. It was estimated that losses of spring and winter wheat alone, caused

by this disease, amounted to about 80,000,000 bushels in 1919. It overwinters and develops during humid summers on old crop refuse, such as straw and stubble and especially cornstalks. From these the spores are blown to the flowering grain. A positive measure of control, frequently amounting to the difference between success and failure, is afforded by plowing that buries all the crop residue and leaves none exposed to scatter the disease. As scab is a disease incident to humid sections, this practice is not in conflict with the necessity in arid sections of leaving trash and stubble on the surface to prevent soil blowing.

CONTROL OF INSECTS BY TILLAGE

The time and character of tillage are important elements in the control of many insects and may be determined or dictated by the necessity for such control. Without entering into a detailed discussion of insect control, a few examples of tillage for that purpose may be given.

Control of the hessian fly is accomplished entirely by tillage and the time of seeding. Wheat that is ruined by the fly should be plowed under as soon as possible, infested stubble should be plowed as early after harvest as practicable, and volunteer growth of wheat should be destroyed. These are items of good husbandry in addition to their value for insect control. Seeding is delayed until after the egg-laying season is past.

The European corn borer overwinters in a dormant state in corn stubble, stalks, and cobs. The number of insects is reduced by plowing under, burning, or otherwise destroying all such refuse before May 1. Plowing for this purpose must be clean, in order that any insects that succeed in emerging from the soil with which they have been covered may find no protection on the surface.

Plowing stubble under deeply after harvest is a control measure for the wheat jointworm. The green bug, or spring grain aphis, is held in check by tillage to destroy volunteer grain during the summer and early fall.

Protection of such crops as corn against cutworms is afforded by plowing about the time or before the eggs are laid in midsummer or early fall. Late fall and winter plowing will destroy many hibernating cutworms as well as such other pests as white grubs.

Plowing stubble land during the fall or early spring is a simple but effective method of fighting grasshoppers. Young grasshoppers cannot penetrate more than 3 inches in fairly compact earth. Cricket eggs are laid singly in the surface inch of soil. If the surface permits, shallow cultivation that exposes the eggs to 3 to 5 hours' drying on a hot, windy day, will destroy them. If the land is plowed deeply, in late fall if possible, the young crickets will be unable to reach the surface.

EFFECT OF TILLAGE ON EROSION

Land use that requires tillage is the basic cause of destructive soil erosion, because it demands the removal of the cover of forest, scrub, or grass that in nature protects the soil. To a large extent the farming system determines the kind and number of tillage operations, the

time they are performed, and the extent to which the soil is protected by cover and incorporated organic matter. Consequently it is of primary importance in the control of erosion.

The loosening of heavy soils by deep tillage facilitates quick penetration and reduces run-off. A coarse granular or cloddy surface intercepts the run-off of water and the movement of soil by wind. In the control of erosion by water, the direction of the tillage is of paramount importance. Tillage operations directed up and down the slope provide natural channels to speed run-off water downhill with its load of soil. Plowing and other tillage operations across the slope, on the contrary, provide a series of obstacles to the flow of water and innumerable pockets, depressions, or furrows in which it is held until it can enter the soil.

Tillage is an important means of preventing wind erosion. The type of tillage used in preparing the land for a crop often determines its susceptibility to this type of erosion. The use of implements that tend to keep the surface cloddy and to leave crop residues on the surface greatly reduces the number of times that the soil is subject to blowing.

Wind erosion is most common in semiarid sections where tillage to conserve moisture is a necessary part of crop production. Without tillage to control weeds, the soil is not likely to reach a moisture condition satisfactory to the growth of a crop. The tillage to conserve moisture introduces some hazard of erosion by wind, but this hazard can be largely overcome by restricting the cultivations to the least number that will accomplish the desired end and using implements that destroy weeds without unduly pulverizing the soil. Where soils have reached a condition of active erosion, either because precautions have not been taken or in spite of them, tillage is the only practicable means of holding the soil in place until a vegetative cover can be established. Such cultivation is usually performed with some implement like a lister, which not only brings clods to the surface but also leaves deep depressions in which drifting soil particles may lodge.

INTERTILLAGE OF GROWING CROPS

Experience has shown that such crops as the small grains and grasses can be grown satisfactorily and most economically by planting them in solid stands so that they cover all the land equally. Such crops by reason of the time and character of their growth ordinarily are able to suppress the weeds that are present among them and are given no tillage while they are growing. Other crops such as corn, cotton, grain sorghums, potatoes, sugar beets, and beans are customarily planted in rows with sufficient space between them to permit cultivation during their growth. Such intertillage is first and primarily for the purpose of killing weeds, although it accomplishes other objects that under some conditions may be important.

If the soil is waterlogged, cultivation is a positive benefit in drying and aerating the soil and thereby promoting nitrification. Heavy soils benefit the most from cultivation for these purposes. Such cultivation is most likely to be needed when the crop is young, and at that time and for that purpose it should be deep and close to the row. Later cultivations should be shallow, as deep cultivation prunes the roots

and interferes with the utilization of the soil near the surface, which contains the most available plant food.

Whereas early cultivations may be for the purpose of drying the surface soil, later cultivation may conserve water by checking run-off and facilitating penetration into the soil. The soil mulch in itself has little effect in preventing the escape of water, but the cultivation that creates the mulch destroys weeds that would use water. When the soil is opened up with cracks through which water vapor could escape, these may be filled or covered by cultivation. The apparent saving of water by this means may not be so great as might be thought, because the soil would not be cracked if there were much water in it to be lost.

Level cultivation is generally preferable to ridged cultivation, because ridging means deep cultivation and root pruning. Some ridging is necessary with potatoes to cover and protect the tubers. In some alluvial bottom land ridging may be necessary with corn, and with some weeds such as morning-glory deep cultivation may be necessary to bury them or restrain their growth.

The labor of intertillage and the total cost of tillage may be reduced by cultivation before the crop is planted. Such tillage firms the soil, prepares a seedbed, and kills weeds while they are young.

TILLAGE operations require tools and machinery, and their effectiveness often depends on picking the right implement for the job. In this article many of the implements now available for these purposes are described. The development and improvement of agricultural machinery is one of the major achievements of modern times, but as the author points out, much remains to be done.

Tillage Machinery

By R. B. Gray[1]

THE manner of handling soils for agricultural purposes depends upon the particular requirement, and involves the use of a wide variety of machinery, ranging from the age-old plow to the more recent and more complex equipment used in digging ditches for drainage purposes and building terraces for the control of soil erosion.

Tillage tools are expected to produce certain effects on the soil directly beneficial to the crop. In recent years the selection of the right equipment has been made much easier by the availability of efficient and reliable machinery to meet almost any need and by the establishment of engineering advisory services by manufacturers and others.

PLOWING

If the action of the moldboard plow is carefully analyzed, the type of plow in relation to soil types and the preparation of these soils for plant growth will be seen. The plow breaks loose or shears off the furrow slice by forcing its "triple wedge" into the soil. These forces produce definite shear planes, called primary and secondary, as the soil is turned. The primary shear planes (fig. 1) extend forward and upward at an angle of 45° with the horizontal plane and at an angle of 45° with the direction of travel of the furrow slice on the moldboard. The soil is thus broken into lumps the size of which depends upon its physical condition. Sandy soils shear easily and heavy soils require considerable force. When the soil is thus broken it is forced up over the moldboard surface, the moldboard surface being warped or twisted for inversion. The turning or inversion effect requires that a secondary set of shear planes at right angles to those first produced

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Figure 1.—Rear view of plow bottom showing furrow slice breaking apart along primary shear planes.

be imposed upon the soil mass, the soil being further pulverized and inverted at the same time.

Sod plows, used where the soil is tied together with a root mass, have long sloping moldboards. If too much force is required to break the soil into pieces or if it will not bend or twist on a steep moldboard surface, the furrow slice will be thrown crosswise instead of being inverted. With a light or sandy soil a steep moldboard is required, because the soil does not have sufficient rigidity to allow its passage over a long surface. Between these extremes are various shapes designed for soils of different resistive properties. The frictional relations between soils and metals are also important, particularly in soils containing much sand or other gritty material. If the soil is not sticky, either chilled cast iron or soid steel may be used; if it is sandy or gravelly, chilled cast iron, which resists abrasion much better, should be used; if it is sticky, soft-center steel is commonly used, but chilled steel may be used in some instances; if it is excessively adhesive, slat moldboards or rods are used in place of the conventional moldboard, so as to reduce the surface area to which the soil can cling. Also abrupt curvatures must be avoided in sticky soils. The English-type plow, in which the moldboard has a convex surface, opens the soil and pushes it over with materially less pressure in the inversion action than the American or digger type.

It is estimated that about 2½ billion horsepower-hours are used annually on farms of the United States for plowing and listing alone. This is practically one-third of all the farm draft work. Census

figures indicate it is equal to the horsepower-hours normally used in the cement-manufacturing industry. With this high power requirement, and the effects on subsequent tillage operations, as well as on crop growth and yields, it is important that this initial step be taken intelligently.

The use of plows—moldboard and disk—is wide and varied and their designs both as to shape and materials have been developed to meet the needs. Under certain extreme conditions, however, present equipment fails to meet requirements and much research is still needed.

Moldboard plows, the type most commonly used, vary in size from 6 or 8 inches in width of furrow cut to as much as 6 feet, the latter being a special ditching plow developed in the West. Probably the majority of moldboard plows range in size from 7 to 18 inches and are single- or two-furrow horse-drawn walking plows, one- or two-furrow sulky (wheeled) plows, horse- or tractor-drawn, and up to probably six-furrow tractor-drawn, although tractors are on the market that will pull as many as fourteen 14-inch moldboard plows.

Where one-mule farming is done, as in many localities of the southeastern Cotton Belt, a single-furrow 7- or 8-inch walking plow is commonly used. This does not permit of plowing more than about 4 inches deep, of covering much trash, or of plowing a very large acreage in a given length of time. It does aerate the soil and cover some of the smaller weeds and trash. This plow, as a rule, is fitted with chilled moldboards and shares to resist abrasive soils. Where scouring difficulties in sticky soils are encountered slatted moldboards are provided. This type of moldboard is also used under similar conditions on larger horse and tractor plows. The hillside plow is so made that the plow bottom can be turned on a longitudinal axis, thus enabling the plowman to go back and forth across slopes always throwing the furrow slice in the same direction. These plows are usually small.

In the larger plows, both horse- and tractor-drawn, there are several different shapes adapted to a variety of soil and field conditions. At one extreme is the breaker type with a long easy-turning moldboard, adapted to virgin or tough sod, for laying the furrow over smoothly in a long ribbon. At the other extreme is the stubble bottom with its short, abrupt moldboard for pulverizing old ground, as in fields of small-grain stubble, and mixing it with the stubble and trash. Intermediate are such plows as the general-purpose bottom, which works well in stubble land, tame sod, or old ground, and is effective in covering trash and weeds; and the black-land bottom, with the mold and the suction of the share so constructed that the plow will penetrate and stay in the ground whether or not the parts scour. The latter is used in black land, "buckshot," and other heavy soils. Slatted moldboards of the stubble type are frequently used in these difficult soils.

With the advent of rubber-tired tractors and the tendency to increase plowing speeds, have come plow bottoms with less abrupt shapes, sometimes called speed bottoms. These shapes, at the higher speeds, effect more or less the same results as the horse-drawn or slow tractor plows.

Adapted for use in irrigated fields where dead furrows are a hin-

drance to controlling the flow of water, in hilly regions, and in irregularly shaped fields, is the special tool known as the two-way plow. As its name indicates, it may plow in either direction and throw all of the furrows one way. It is fitted with both right- and left-hand bottoms—one of each on horse-drawn plows and generally two of each on tractor-drawn (fig. 2). This plow accomplishes the same results as the hillside plow previously described. In European countries frequent use is made of a balance plow—one set of shares in the ground, when in operation, the other in the air with the plow beams at an angle of some 40° with the horizontal but facing in the opposite direction. When the direction is reversed the set of plows in the ground is raised and the other is lowered.

As mentioned before, conditions not only determine the shape but

FIGURE 2.—A two-bottom two-way plow in use in California.

the size of the bottom. It is generally considered that a plow does its best work when operating at a depth one-half to six-tenths of its normal width at normal speed under good plowing conditions. For root crops, such as sugar beets, potatoes, and mangels, at least a 14-inch plow is necessary and a 16- or 18-inch plow may be better. The 14-inch is the common size of tractor plow. If much trash is to be plowed under, as a rank growth of cornstalks, plows with 16- and 18-inch bottoms and large clearance are better. For the control of the corn borer or other pest where complete coverage of trash is necessary, large bottoms of the general-purpose style are best.

Complete coverage of trash and weeds is facilitated by the use of attachments. The rolling colter and jointer used together cut the edge of the furrow slice cleanly, pare off a corner of the slice with its projecting grass or weed growth, and deposit it in the furrow where

it is covered by the furrow slice. A self-alining disk jointer has been developed by the Bureau of Agricultural Engineering to take the place of the rolling colter and jointer and is especially adapted to trashy fields. Sheet-metal trash guides, also designed by the Bureau, guide trash under the furrow slice as it is turned (fig. 3). The self-alining disk jointer may soon be put on the market by manufacturers. Weed rods or long wires are sometimes attached to plows to facilitate good coverage of cornstalks or tall weeds. For the coverage of broomcorn stalks, sweetclover, and stubble, broomcorn spring attachments are used. These attachments press the stalks down, and if a notched

FIGURE 3. Trash guides drag stalks and trash into position to be completely covered by the furrow slice. The result is a clean job of plowing, a big factor in insect control, particularly in keeping down the European corn borer.

colter is used in conjunction with them, the notches catch the trash so it is crowded down and not pushed ahead as it frequently is with the smaller plain disk colters.

In semiarid farming regions and where soil is underlain with hardpan, subsoil plows are used to open up the ground for deeper moisture penetration and to prevent souring of the soil. Attachments for moldboard plows as well as so-called chisels are also used for this purpose. Some chisels penetrate 18 inches or more and are used in the deeper soils to open them and break hardpan to let in more surface water.

Disk plows (fig. 4) work best in soils so dry and hard that moldboard plows penetrate with difficulty, and in sticky soils, such as gumbo, where moldboards do not scour. They may also be used effectively in loose soil and where there are many roots, shrubs, and bushes. Disk

plows are of both tractor- and horse-drawn types, with from one to seven or eight disks. The most common tractor and horse sizes are 24 and 20 inches, respectively, but some disks are as large as 30 inches in diameter. The depth of plowing with these plows may be varied from 4 to 16 inches and the width cut per disk from about 7 inches to 12 inches. On some disk plows the angle of the disk with the vertical plane may be varied for better penetration, pulverization, and turning. Some of them are made to permit of widening the space between adjacent disks for better handling of heavy trash.

For use in ordinary plowing there are individual stationary paddle-type scrapers for cleaning the disks and a revolving-type disk scraper for use in sticky soils.

The one-way disk plow (variously known as the one-way, Wheatland, harrow, disk tiller, cylinder, and vertical disk plow), which might be called a combination of a disk plow and disk harrow, is used in many sections for summer-fallow work. In fallow land it should be used as early as possible in the spring to start weed growth by loosening the soil and causing earlier warming, and throughout the summer to destroy weeds. When used in the stubble fields of the Wheat Belt it leaves the stubble well mixed with the soil but with enough exposed to retard blowing. (This tool has become popular within the last few years, but it should be used with discretion, since excessive use of it in certain localities fines the soil to the extent of increasing losses from blowing and washing.) Because the disks of this plow all face one way, it works with its axis at an angle—between 35° and 45°—and the thrust is taken by specially angled front and rear wheels. The cutting width of these machines ranges between 4 and 10 feet, the disk sizes from 20 to 26 inches, and disk spacings from 6 to 10 inches. In the southeastern Cotton Belt, where soil-building winter legumes are grown, tests conducted by the Bureau of Agricultural Engineering in 1936 and 1937 indicate that most effective killing of the legumes in the spring can be done with this type of tool with a disk spacing of 10 to 12 inches.

Middlebusters and listers are similar in appearance to a double plow with a right- and a left-hand bottom mounted back to back. They are used in the preparation of ridges in which to plant cotton, potatoes, sweetpotatoes, and other crops bedded in rows. Frequently the land is first plowed (flat broken) then later ridged with the middlebuster. This tool is also used to clean out the middles, break out the rows, and sometimes rebust. In the semiarid regions it is used for placing the soil in ridges to hold moisture and prevent blowing. In these regions, too, this type of tool is mounted on a planter called a lister and wheat or corn is planted in the resulting furrow. A basin-forming lister attachment (fig. 5) which automatically forms dams at regular intervals in the furrow to hold moisture for the corn that is planted at the same time, was developed cooperatively by the Bureau of Agricultural Engineering and the Iowa Agricultural Experiment Station. Applications of this device are being used extensively in semiarid regions including areas suffering much in recent years from excessive soil blowing.

Listers and middlebusters (busters or breakers) are available in walking, riding, and tractor types of from one to five rows, and,

according to the type, in furrow sizes from 8 to 14 inches. There is also a 20-inch size for opening up furrows in which to plant sugarcane.

HARROWING

As plowing may be considered the primary tillage operation, harrowing may be termed the secondary operation, the purposes of which are to level the plowed soil, fine and compact it, and destroy weed seedlings.

The disk harrow is probably the most useful of all harrows, ranking next in importance to the plow (fig. 6). After spring plowing as a rule the ground should be disked immediately. Fall-plowed land should preferably be disked the following spring as soon as the land is dry enough to work. Disking pulverizes the soil, reduces large air

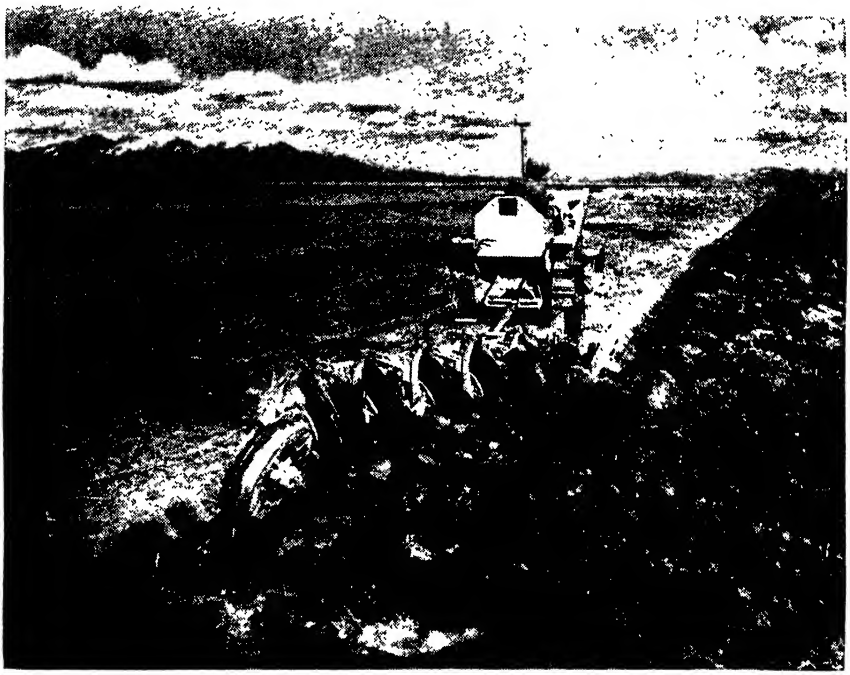

FIGURE 4.—A five-bottom disk plow preparing land 10 inches deep. The disks are 26 inches in diameter.

spaces, and helps form the seedbed. Sometimes the disk is drawn along behind the plow, making a once-over operation. Frequently fields can be put in good condition for planting small grain by double disking alone. Some makes of disks are provided with depth gages which prevent too deep penetration in light and sandy soils, such as are found in fruit-growing areas in Florida and other regions.

The penetration of a disk harrow may be regulated by angling the gangs; the greater the angle the greater depth the disks will penetrate. Disk harrows may be generally divided into horse-drawn and tractor-drawn. The horse-drawn, as a rule, are single cut, and in order to leave the soil level the land must be disked in the opposite direction.

Double-cut disk harrows—two gangs in front and two in the rear—keep the soil level. Both 16- and 18-inch disk sizes are available and widths of cut range from 4 feet if horse-drawn to 20 feet if tractor-drawn.

Special disk harrows with distance between gangs adjustable for cultivating under trees in orchards are available in several sizes, as are also cutaway disks—with sections of the periphery in the disk cut out—for conditions where extra deep penetration is necessary and thorough pulverization is not essential.

The spike-tooth harrow (peg-tooth, smoothing) aids materially in breaking clods and leveling the ground (fig. 6). It is also effective in covering seeds. The desired depth of penetration may be obtained by adjusting the angle of the teeth—the nearer to vertical, the deeper the penetration. Under extreme conditions additional penetration

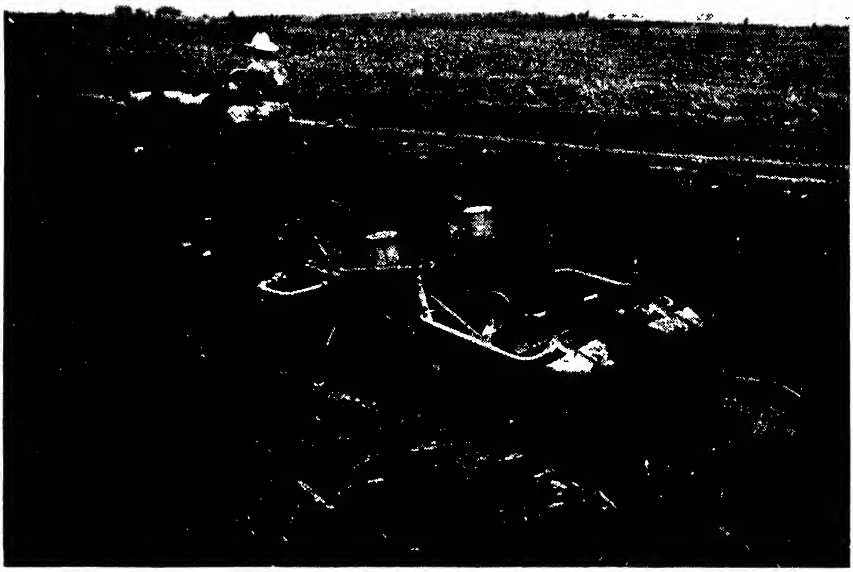

Figure 5.—A basin-forming lister attachment which forms dams in the furrow to hold moisture for corn planted at the same time.

may be obtained by the addition of suitable weights. The width of cut ranges from the size of a single section, which is about 5 feet, to about 25 feet when several sections are pulled abreast. On some types the teeth are rigid within the section while in others the individual bars are free to conform to the surface of the ground, and in still others, through links, the individual teeth are free to follow the ground contour.

The spring-tooth harrow does not have so wide an application as the peg-tooth harrow, but it is capable of penetrating sufficiently to tear up deep clods. With the flexible teeth little damage is incurred from butting stones or other obstructions. By the use of special types of teeth, this tool may be used to advantage in digging out roots of quackgrass and other noxious weeds or in cultivating alfalfa. It is

available in two types, mounted and unmounted. The former is carried on a frame supported on wheels while the latter slides along the ground. Levers are provided for changing pressure on the teeth which determines depth of digging. Generally the sections of this harrow have three rows of teeth staggered, and the harrow is available in working widths of from about 5 to about 17 feet in one to six sections.

Clod crushers and mulchers are used to break up lumps left by harrows and to compact the soil, thereby eliminating large air spaces which destroy capillarity and interfere with seed germination. Various rollers are used for this purpose. The plain roller is often used to compact grassland that has heaved during the winter leaving pockets detrimental to the growth of the grass. The roller is frequently used in alfalfa fields also.

The corrugated roller—single and tandem—is used to firm the soil after plowing and to break up clods (fig.7). Tandem rollers are

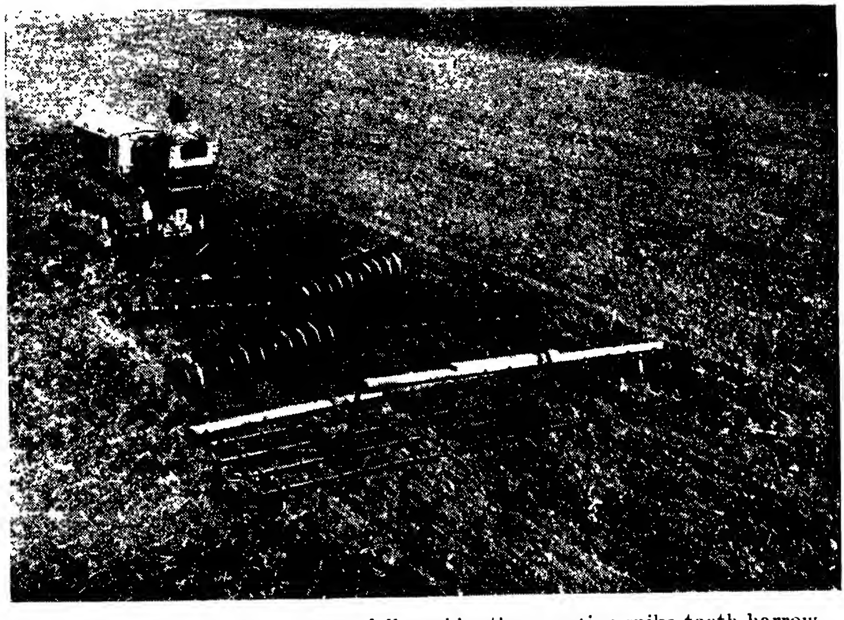

FIGURE 6.—Double disk harrow followed by three-section spike-tooth harrow.

especially effective in crushing clods as the ridges of the second roller split the ridges left by the first. Generally the front rollers are about 3 inches larger in diameter than the rear ones, and when clods are very hard the rear rollers may be raised and fixed in position so that their weight is added to that of the front ones. After wheat has been sown this type of roller compacts the soil around the seed to improve germination, and the corrugations left on the surface help prevent soil blowing. The working width of these tools ranges from 3 feet single and tandem to as much as 10 feet.

Another type of effective clod crusher and packer is one made up of a series of sprockets loosely fitted at the hub and mounted between

successive pairs of sharply ridged rollers. In moist soil the lagging of the sprocket members tends to prevent clogging of the rolls. These are available for use with both horses and tractors and range in size from 4 feet to 15 feet.

Other types of clod crushers which produce similar results are also available.

For preparing a seedbed in one operation there is available a

Figure 7.—The corrugated roller firms the soil and breaks up clods.

machine with tines rapidly revolving in a vertical plane, which pulverizes the soil as the tool moves along the field. This is mainly for spring work in market-gardening districts, greenhouses, nurseries, etc., and is available in sizes ranging from a 14-inch width of cut to 48 inches. The depth may be varied from very shallow to about

10 inches. In England there is an implement with a series of revolving blades which prepares a seedbed in one operation as it moves across the field stirring the soil to a depth of 12 to 18 inches and breaking up any hardpan. It does not bring up subsoil or dormant weed seeds and is especially useful in preparing land for root crops, but it requires a very large tractor.

CULTIVATION

Weed destruction is the primary purpose of cultivation, but the method and degree of cultivation affect the quality and yield of the crop. Except for combating the longer rooted perennial weeds, shallow cultivation is preferable. Deep cultivation, particularly after the plants have considerable root spread, tends to cut off crop roots, a practice particularly bad in dry periods.

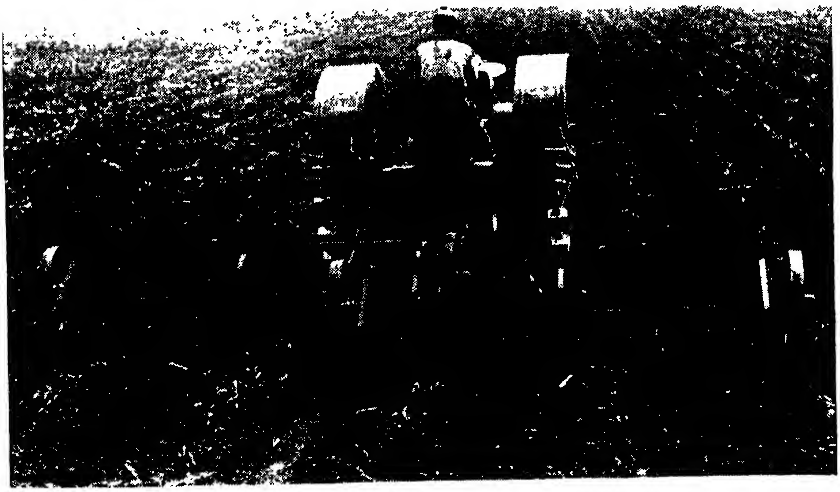

FIGURE 8.—The rotary-hoe cultivator, having wheels with projecting fingers, is used on corn and other row crops in the early stages.

Probably the most common cultivation tool is the shovel cultivator. In their simplest form the shovels are short, narrow, slightly curved, pointed steel pieces which dig into the soil according to the pressure applied. For very shallow cultivation there are sweeps of various widths. These cultivators are available in sizes ranging from the one-horse type up to two-row horse- or tractor-drawn and three- and four-row tractor-mounted machines. One-horse and one-row equipment may be either for walking or riding. The number of shovels used per gang, as well as the type, depends on the crop and on soil characteristics. The shovels or sweeps are sometimes replaced by disks or disk hillers when it is desirable to move a considerable

quantity of soil or where trash and vines are to be cut to prevent clogging the cultivator. Sections similar to spring-tooth harrows, flexible-tooth weeders, or flat-surface cultivator blades may also be used in place of shovels.

The rotary hoe (fig. 8), consisting of a series of 18-inch hoe wheels fitted with radially projecting fingers is useful in the early growth stages of corn and other row crops. Its success, however, depends on getting into the field before the weeds have made as much growth as the crop; otherwise the crop plants also would be kicked out. It appears to be most effective at speeds somewhat higher than the average speed at which a horse walks. This tool is effective also in breaking crusts resulting from hot sunshine after a beating rain. It

Figure 9.—A cross blocker used in beet fields for reducing the number of seedlings previous to thinning. The sweeps or knives may be adjusted for any desired distance between plants.

is available for use with horses or tractors and is frequently used in combination with other cultivating tools. The sizes range from 7 to 21 feet in width and harrows of some sizes are built in tandem.

In cooperative studies on corn-production machinery made by the Bureau and the Iowa Agricultural Experiment Station, the best results in cultivation of early, surface-planted corn were obtained with a cultivator fitted with a pair of rotary-hoe wheels near the row and six sweeps between the rows. In weedy corn a cultivator with two pairs of disk hillers and one pair of sweeps per row gave best results.

For cultivating crops with narrow row spacing—beets and beans

for example—there is a special cultivator which covers at one time the same number of rows as planted at one time by the drill. For the cross blocking of beets—reducing seedlings previous to thinning—the sweeps or knives attached to the beam of the cultivator frame may be shifted to leave any size block desired (fig. 9). In some foreign countries the same type of tool is used for cultivating wheat.

The so-called field cultivator, with long slender teeth spaced about 3 inches apart, may be used for cultivating practically any crop when weeds are small and not firmly rooted. This tool, however, is not especially effective in wet or firm soil. The rod weeder is used in cultivating fields where weed growth is to be kept down and a good seedbed maintained for the next crop (fig. 10). The working element of this machine is a horizontal rod at right angles to the direction of travel, driven by one of the supporting wheels, which revolves at a depth of 1 to 5 inches below the soil surface. The roots and weeds are wrapped around the rod and pulled out. This weeder is frequently

Figure 10.—A rod weeder. A horizontal rotating rod (not visible in the picture) is pushed through the loosened soil at a depth of 1 to 5 inches. Weeds are wrapped around the rod and pulled out.

used in fallow land and ranges in working width from 8 to 12 feet in single units to greater widths up to 36 feet obtained by combining two or more units.

While present equipment does effective work against many of the more common annual weeds, certain perennials are very tenacious and in some localities are overruning farms and making them unproductive. More research on the habits of such weeds is needed to determine the best time to attack them. With this information at hand, existing equipment can be used to better advantage and improved equipment developed.

For the use of market gardeners, horticulturists, amateur gardeners, and growers with small acreages there is a wide variety of tillage tools available to fit practically every requirement. These include garden tractors—both walking and riding, ranging in size from 1 horsepower to a maximum of 10—capable of pulling single-furrow plows of 6-inch size to a maximum size of 12 inches. Such tractors are provided

with various types of attachments to handle ordinary cultivating and other tillage operations.

Hand-operated tools, such as the push-type cultivator and seeder, as well as a wide assortment of small tools for specific tillage purposes, should also be mentioned.

It is impossible to discuss in this article the many details of construction and use of such a wide variety of equipment, or to enumerate all the tillage tools on the market, but further information may be had by writing manufacturers for literature covering the particular requirement. More fundamental information is needed on how tillage tools should be used for maximum effectiveness in various soils and on different crops, and some research is now going on in this field.

STUDIES OF TILLAGE MACHINERY AFFECTING COTTON AND CORN CROPS

The Cotton Crop

Approximately one-third of the cost of producing cotton is made up of seedbed preparation, planting, cultivating, and hoeing. These are all tillage operations, and unless planned and executed advantageously they may hinder the farmer in following a diversified crop program and cut down his yield of cotton as well. The joint efforts of many of the scientific branches of agriculture are needed to determine the relation between crop growth and soil manipulation, so that the manufacturer, on the basis of such information, can provide better tools.

Work along this line on one soil type—Red Bay fine sandy loam—was started in Alabama in 1932 by the Bureau of Agricultural Engineering and the Alabama Agricultural Experiment Station. Measuring results in cotton production, labor, power, and machine requirements in 37 conventional methods of seedbed preparation, the studies are intended to evaluate several methods of cotton planting and 24 methods of cultivation.

In seedbed preparation it was found that the highest average yield over the period, 1,333 pounds of seed cotton per acre, was obtained on the plots plowed or "busted" 8 inches deep in the winter, when the soil was relatively dry, and then allowed to settle and mellow until spring. At planting time the soil thus manipulated was cloddy. Approximately 30 percent of the soil mass to the 8-inch depth was in clods more than 1 inch in diameter with an apparent specific gravity at the 6-inch depth of 1.22. (Apparent specific gravity is a measure of a soil's relative compactness and is expressed as the ratio of the weight of a given volume of water to that of an equal volume of dry soil. An apparent specific gravity of 1.5 to 1.6 is normal for this type of soil when undisturbed.) Eleven man-hours and 38.8 mule-hours (26.3 calculated horsepower-hours) per acre were used in this method, which involved four operations—cutting stalks, plowing, bedding, and smoothing. The crops grown on plots treated in this manner were less affected by drought than those receiving other treatment.

While the above method caused the soil to maintain an open granular structure throughout the crop season, certain other methods tended to destroy desirable soil structure by excessive pulverization. In this same depth series, six operations—cutting stalks, "busting"

rows, subsoiling, listing back, "busting" the middle, and smoothing—produced 1,258 pounds of seed cotton per acre in a finely pulverized seedbed with a specific gravity of about 0.9. More than 18 man-hours and 71.2 mule-hours (41.3 calculated horsepower-hours) per acre were used.

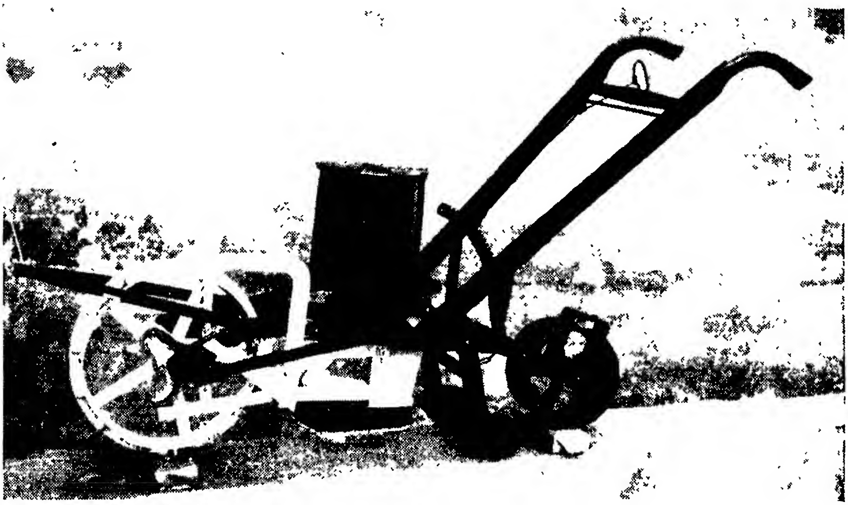

FIGURE 11.—The variable-depth cotton planter. Note the three-lobed cam on the side of the front wheel which causes the seed to be planted at varying depths.

Still another method in the 4-inch depth series produced a finely pulverized seedbed and showed a further reduction to 1,071 pounds with the use of 25.8 man-hours and 33 mule-hours (21.3 calculated horsepower-hours) per acre.

The usual farm practice is to wait until spring to start seedbed

FIGURE 12.—Part of row of young cotton plants grown from seed put in with the variable-depth planter.

preparation work and then, by shallow working, produce a nicely rounded loose seedbed just before planting. This tends to produce a plow sole. The first method, the one producing the cloddy, open seedbed, is to be recommended on this particular soil type.

Soils appear to vary in their ability to assume a semipermanent structure that will aid crop production. The methods found best on

the Red Bay fine sandy loam may not be best for other types. It would therefore seem advantageous to agriculture that investigations of this nature be carried on not only with cotton in other soil types but with other crops in other regions.

In the neighborhood of Montgomery, Ala., where these seedbed preparation studies were made, about 50 percent of the cotton has to be replanted each year. By using the Bureau's variable depth planter, which plants cotton in depths varying from 0 to 1½ inches in cycles of about 18 inches, no replanting was necessary. Before planting the seedbed was cut to the desired height with a sweep shaped to give the bed a slight crown (figs. 11 and 12).

Cotton-cultivation studies indicated that row cultivation should be shallow and just sufficient to keep down the weeds. The recommendation, based on the data and on land free of Johnson grass, nutgrass, or large weeds, is to start early cross-row cultivation soon after planting to keep down the weeds, break the soil crust, and help bring the cotton to a stand of strong plants. Chopping was followed by shallow row cultivation frequent enough to control weeds.

In the South the growing of winter legumes as a soil-building crop has proved profitable. Extension of this practice depends upon the ability of the farmer to turn under a greater acreage of cover crops in the limited time available for such work. Studies conducted on one soil type by the Bureau during the 1936 and 1937 seasons show that the method of planting the legume has a marked effect on its rate of growth and on the stand. They show also that the method of incorporating the crop debris affects the yield of the following cotton crop by as much as 300 pounds of seed cotton per acre, and that the incorporation of organic matter affects the cost of preparing the seedbed for the year following the first crop of cotton after the legume is plowed under. This is evidently due to the effect of the organic matter on the soil structure. The results indicate that the power for preparing an optimum seedbed may be reduced 50 percent or more. Effective equipment appeared to be the 14-inch moldboard plow operating at 3 miles per hour and plowing 4 inches deep, or the vertical disk plow with 10- or 12-inch spacing of disks at 3 to 4 miles per hour and at a depth of about 4 inches. The mule plow with colter and covering wire was also effective. In many cases where the plants were insufficiently covered, following with a double-disk harrow accomplished the purpose. Disking previous to using the vertical-disk or moldboard plow resulted in better coverage.

The Corn Crop

In the cooperative studies with the Iowa Agricultural Experiment Station extending over several years, it was found that for the primary operation in preparing a seedbed for corn the substitution of cheaper operations adversely affected yields. Such tools as the one-way disk and feed cultivator were used for comparison.

The moldboard plow was also compared with another type of plow having the rear half of the moldboard replaced with a power-driven rotating member fitted with blades for pulverizing the furrow slice as it leaves the stub moldboard. Although the amount of seedbed preparation done subsequent to plowing was the same with both plows, no

significant difference in yield was noted in either case, except under unusually wet or dry conditions when the results with the ordinary plow were slightly inferior.

The secondary operation following the plowing consisted in breaking up large clods and filling any large air spaces in the soil, planing off irregularities in the soil surface so that planters and cultivators would operate at a uniform depth, and killing weed growth up to the time of planting. In central Iowa this work is usually done with the disk harrow and the lever type of spike-tooth harrow. In localities infested with quackgrass or Canada thistle, a spring-tooth harrow or a field cultivator is preferred over the disk harrow because of its action in dragging out the weed root runners. Under some conditions the field cultivator is preferred with sweeps or duckfoot shovels instead of the narrow pointed shovels.

An experiment comparing the work of the duckfoot field cultivator with that of the disk harrow was conducted for 3 years. Results showed no significant difference in weed control, stand, or yield in any year. Little difference in energy expenditure was noted—for 3-inch depth of cultivation a draft test showed a draft of 105 pounds per foot of width for the field cultivator compared to 95 pounds for a single-disk harrow. The field cultivator dragged out and left on the surface some of the cornstalks and other trash that had been covered in plowing and left many clods on the surface. The disk harrow improved the trash coverage and left the surface more finely pulverized. The lever type spike-tooth harrow was used for the lighter tillage operations. Previous observations had shown that the spike-tooth harrow was generally preferable to other machines tried for the lighter operations in preparing the seedbed. A spring-tooth weeder was inferior to the harrow in breaking clods and in leveling or smoothing action (planing). A land roller, or cultipacker, broke clods, packed the surface, and killed small weeds under dry conditions, but it had very little planing action and did not work well except when the surface soil was dry. A rotary hoe was equal to the harrow in killing weeds and breaking large clods, but it had practically no planing action. A rotary-hoe section was found to be preferable to a harrow section for use in combination with a plow, especially if the soil contained excess moisture.

More comprehensive studies with machines and methods of preparing the seedbed were started in 1937. For the primary operation, comparison was made of deep plowing, shallow plowing, blank basin listing (not planting at the time the basins were made), chiseling, and check plots on which the primary operation was omitted.

Based on 1 year's work only, shallow fall plowing 4 inches deep produced 6 bushels per acre increase over check plots that were not plowed. Deep plowing (8 inches) produced a slightly lower yield than shallow plowing. Blank basin listing caused a yield increase of 1.5 bushels per acre over check plots, while chiseling 10 inches deep produced no benefit.

Five methods of secondary preparation of plowed ground (that is, work after plowing up to the time of planting) were compared. Methods involving a minimum amount of work on the soil resulted in about 25 percent decrease in yield. On fall plowing the best yields

were obtained on plots that were covered three times with tandem disk and spike-tooth harrow—about twice as much work as ordinarily done by farmers in preparing a seedbed. On spring plowing a single coverage with tandem disk and spike-tooth harrow produced equally as good yields as a larger amount of work. Results emphasize the importance of having the soil entirely free of weed growth at the time of planting.

THIS article tells why organic matter in the soil may be considered our most important national resource. The author describes how it furnishes fuel for "bacterial wrecking crews" and how it is turned into plant nutrients. He shows that many of our farm practices have enormously reduced the supply originally present in the soil and warns that we must expect a permanently lower level of agricultural efficiency if we do not take steps to counteract this waste. The problems involved in maintaining an adequate supply of organic matter in the soil are dealt with from a practical standpoint.

Loss of Soil Organic Matter and Its Restoration

By WILLIAM A. ALBRECHT [1]

CENTURIES before there was any science that acquainted people with the intricacies of plant nutrition, decaying organic matter, as in manure or other forms, was recognized as an effective agent in the nourishment of plants. The high productivity of most virgin soils has always been associated with their high content of organic matter, and the decrease in the supply with cultivation has generally been paralleled by a corresponding decrease in productivity. Even though we can now feed plants on diets that produce excellent growth without the use of any soil whatever, yet the decaying remains of preceding plant generations, resolved by bacterial wrecking crews into simpler, varied nutrients for rebuilding into new generations, must still be the most effective basis for extensive crop production by farmers. Soil organic matter is one of our most important national resources; its unwise exploitation has been devastating; and it must be given its proper rank in any conservation policy as one of the major factors affecting the levels of crop production in the future.

The stock of organic matter in the virgin soils taken over by the homesteading pioneers was a heritage from an extensive past. Its accumulation in our northern soils began with the recession of the last glacier, possibly some 25,000 years ago, and continued long enough to ripen the residues into compounds that were ready to be used quickly by growing plants.

With the departure of the ice sheet and the consequent general rise in temperature, the glacial residue of pulverized rock offered minerals in solution for plant growth. As the plants found nitrogen to combine with these minerals, they grew, died, and began to accumulate in the soil. Then, as the rate of rock weathering increased, bringing a larger supply of soluble minerals, the accumulation of plant remains became

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correspondingly larger. Finally, when the rocks were more completely weathered so that they provided less mineral stock, or very little, an equilibrium point was reached at which the accumulated organic matter held in combination most of the minerals that could be turned into soluble forms. Thereafter the supply of soluble minerals became a limiting factor in plant growth.

Wherever there was poor drainage and limited aeration of the sod cover, or where there were heavily wooded soils of relatively level, glaciated topography, more complete simplification of this accumulated store of plant nutrients was very slow. In other words, the organic matter that held the major stock of previously mobile nitrogen and minerals now kept these essentials stored in compounds not simple enough for prompt consumption by growing plants. This represented a very large supply of nutrients not far from the condition in which growing plants could use them. Unable to decay completely or to accumulate much more, they were poised as it were for rapid conversion, when a slight change in conditions occurred, into forms of maximum utility for plant growth.

But with the removal of water through furrows, ditches, and tiles, and the aeration of the soil by cultivation, what the pioneers did in effect was to fan the former simmering fires of acidification and preservation into a blaze of bacterial oxidation and more complete combustion. The combustion of the accumulated organic matter began to take place at a rate far greater than its annual accumulation. Along with the increased rate of destruction of the supply accumulated from the past, the removal of crops lessened the chance for annual additions. The age-old process was reversed and the supply of organic matter in the soil began to decrease instead of accumulating.

FUEL FOR THE PLANT-FOOD PRODUCTION FACTORY

Organic matter may well be considered as fuel for bacterial fires in the soil, which operates as a factory producing plant nutrients. The organic matter is burned to carbon dioxide, ash, and other residues. This provides carbonic acid in the soil water, and the solvent effect of this acidified water on calcium, potassium, magnesium, phosphates, and other minerals in rock form is many hundreds of times greater than that of rain water. At the same time the complex constituents of the organic matter are simplified, and nitrogen in the ammonia is released and converted into the nitrate form. This, very briefly, is the complicated process of decomposition, from which carbon dioxide results as the major simplified end product, together with a host of others in smaller amounts. This gas is released in such large quantities from the soil that the supply in the atmosphere over the earth is maintained at a constant amount.

Decomposition by micro-organisms within the soil is the reverse of the process represented by plant growth above the soil. Growing plants, using the energy of the sun, synthesize carbon, nitrogen, and all other elements into complex compounds. The energy stored up in these compounds is then used more or less completely by the micro-organisms whose activity within the soil makes nutrients available for a new generation of plants. Organic matter thus supplies the "life of the soil" in the strictest sense.

When measured in terms of carbon dioxide output, the soil is a live, active body. An acre of the better Corn Belt soil in Iowa (*365*)[2] or northern Illinois, for example, exhales more than 25 times as much of this gas per day as does an adult man at work. Such a soil area burns carbon at a rate equivalent to 1.6 pounds of a good grade of soft coal per hour. The heat equivalent evolved in the same time would convert more than 17 pounds of water to steam under 100 pounds pressure. A 40-acre cornfield during the warmer portion of a July day is burning organic matter in the soil with an energy output equivalent to that of a 40-horsepower steam engine; every acre, in other words, may be roughly pictured as a factory using the equivalent of 1 horsepower. Organic matter is the source of the power without which the plant-food elements could not be changed to usable forms.

SUPPLY OF VIRGIN SOIL ORGANIC MATTER DECREASING

The depletion of the supply of organic matter by cultivation is well illustrated by the report of a study made by Jenny (*185*) in central Missouri in which an undisturbed virgin prairie soil was compared to an adjoining field cropped to corn, wheat, and oats for 60 years without the addition of manure or fertilizer. No erosion had taken place, yet 38 percent of the organic matter represented by the virgin soil had been lost during that period because of cultivation. As a consequence of this loss in organic matter, the soil structure was modified to an extent that might be represented by reducing the number of granules that were the size of particles of sand by 11 percent and increasing the number that were the size of clay particles by 5.5 percent. The loss of organic matter represents soil compaction, which hampers the circulation of air and water and hinders tillage operations at the same time that the function of the soil in plant nutrition is disturbed. Thus in but 60 years, more than one-third of the organic matter, representing centuries of accumulation, was destroyed and the efficiency of the soil for crop production was reduced.

Resulting Loss in Nitrate Nitrogen

Soil organic matter is the source of nitrogen. In the later stages of decay of most kinds of organic matter, nitrogen is liberated as ammonia and subsequently converted into the soluble or nitrate form. The level of crop production is often dependent on the capacity of the soil to produce and accumulate this form of readily usable nitrogen. We can thus measure the activity that goes on in changing organic matter by measuring the nitrates. It is extremely desirable that this change be active and that high levels of nitrate be provided in the soil during the growing season.

A study of the nitrate levels under corn in a Missouri silt loam during 13 years reveals a gradual decline in the production of nitrates (*5*). During the first 5 years of the test this soil increased its nitrates in the spring to the maximum of more than 20 pounds per acre as early

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

as May. During a similar period only 2 years later, this maximum had been reduced to 18 pounds, and it was not attained until June; 3 years later the maximum was less than 16 pounds, attained in July; and 3 years after that, the maximum of 13 pounds was not reached until August (fig. 1). During continuous cropping to corn without the addition of organic matter, the maximum nitrate accumulation

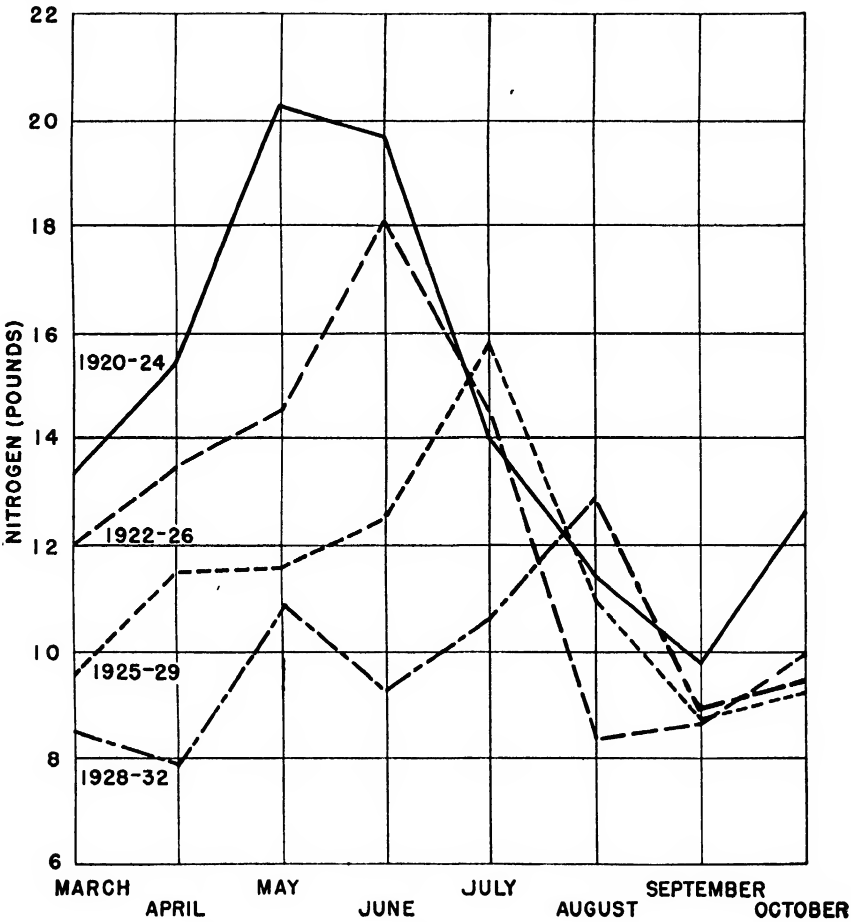

FIGURE 1.—Declining seasonal levels of nitrates and later seasonal maxima with continued cropping to corn. (Averaged for different succeeding 5-year periods.)

dropped to 65 percent of that in the initial period, when the land had been in sod for some time. In other words, though this soil had been in corn continuously for only 13 years—which might seem equal to 52 years of a 4-year rotation, with one crop of corn every 4 years—its nitrate-producing power, or its capacity to deliver this soluble plant nutrient, had been reduced by 35 percent.

Such pronounced exhaustion is not limited to the corn crop, which is readily associated with intensive tillage. The same thing is true in

the case of wheat. Its exhausting effects measured in the same study (*5*) and shown in figure 2, were even greater than those of corn. The nitrate level under wheat was constantly lower than under corn for the corresponding period.

Concurrently with the foregoing measurements showing the decline of nitrates, careful chemical analyses were made of the same kind of soil nearby under fallow conditions with an annual spring plowing. The surface soil alone lost 2,300 pounds of organic matter per acre, as

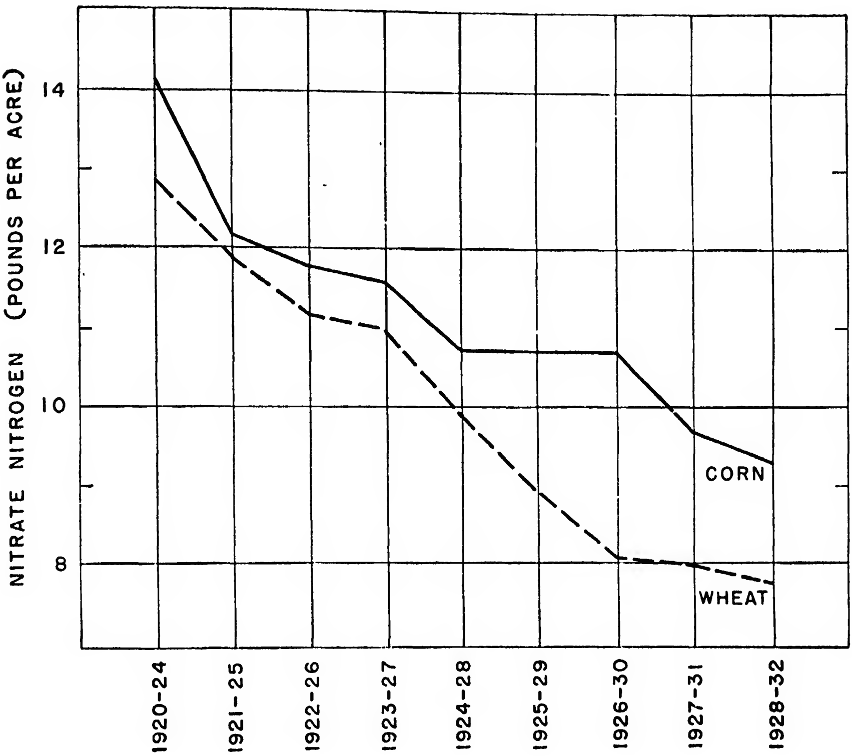

FIGURE 2.—Declining nitrate nitrogen levels in soils in wheat and in corn as advancing 5-year season averages.

shown in figure 3 (*4*).. A nearby plot in a 3-year rotation of corn, wheat, and clover, with all the crops removed during a period beginning 2 years earlier and extending 2 years longer— a total of 17 years—lost 800 pounds of organic matter.[3] Regardless of the presence or absence of a crop, the failure to add organic matter and regular tillage of the soil mean a depletion of the original stock of organic matter at a very significant rate, even where there is no erosion. Where erosion removes the body of the surface soil itself, the rate of depletion is much greater.

[3] From unpublished data supplied by M. F. Miller' Missouri Agricultural Experiment Station.

Lower Crop Yields and Land Values

In addition to carrying nitrogen, the nutrient demanded in largest amount by plants, soil organic matter either supplies a major portion of the mineral elements from its own composition, or it functions to move them out of their insoluble, useless forms in the rock minerals into active forms within the colloidal clay. Organic matter itself is predominantly of a colloidal form resembling that of clay, which is the main chemically active fraction of the soil. But it is about five times as effective as the clay in nutrient exchanges. Nitrogen, as the largest single item in plant growth, has been found to control crop-production levels, so that in the Corn Belt crop yields roughly parallel the content of organic matter in the soil (*184*). On a Missouri soil with less nitrogen than that corresponding to 2 percent of organic matter (40,000 pounds of organic matter per acre of plowed surface soil) an average yield of 20 bushels of corn per acre can hardly be expected. For yields approaching 40 bushels, roughly double the amount of organic matter is required. With declining organic matter go declining corn yields and therefore lower earnings on the farmer's investment. Thus the stock of organic matter in the soil, particularly as measured by nitrogen, is a rough index of land value when applied to soils under comparable conditions. According to studies in Missouri, for example, the lower the content of organic matter of upland soil, the lower the average market value of the land.

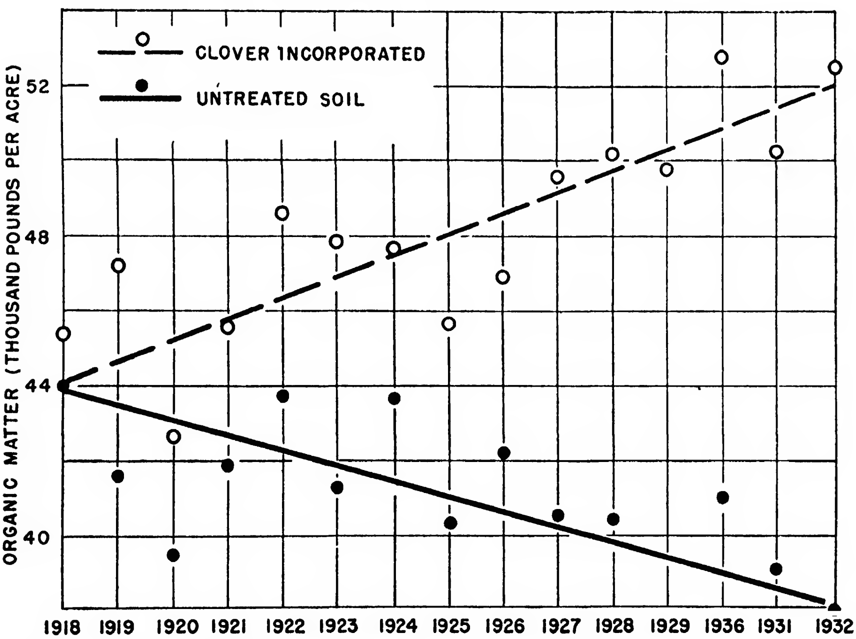

Figure 3.—Decrease of organic-matter content in a fallow, untreated soil in contrast to the gain in soil treated with 2½ tons of red clover annually, representing over 500 pounds annual increase in organic matter per acre.

PROBLEM OF MAINTAINING A LIBERAL SUPPLY OF SOIL ORGANIC MATTER

Though the rapid depletion in the Corn Belt, for example, of the soil organic matter and soil fertility in the pioneer period of a hundred years may be alarming, there is consolation in the fact that this high rate of depletion will not continue. As is true for all biochemical processes, the early rate of consumption is rapid, which gives a sudden decrease. Then the rate of consumption falls off, so that the loss in the second period will perhaps be less than half that in the first. In the third stage the loss will possibly be half that of the second. Long-continued experiments, accompanied by soil analyses, prove that the organic-matter content of a soil will reach a fixed level characteristic of the surrounding climatic conditions. After a period of heavy loss, then, we may expect a fairly constant level during a long period of continued cultivation. This situation is well illustrated by the decline in nitrogen content shown in figure 5 of the article, Soil Nitrogen (p. 369). In other words, we may anticipate a further decline in productivity from the present relatively high levels, followed by a more constant level, which will be proportionate to the lower content of organic matter, determined by the environment in each particular region.

Maintaining Versus Increasing the Organic Matter

The following questions naturally arise: What should be the content of organic matter in a soil? Should the present level be raised or merely maintained economically? These are questions of decided significance in determining policies in soil management.

Attempting to hoard as much organic matter as possible in the soil, like a miser hoarding gold, is not the correct answer. Organic matter functions mainly as it is decayed and destroyed. Its value lies in its dynamic nature. A soil is more productive as more organic matter is regularly destroyed and its simpler constituents made usable during the growing season. Its mere presence in the soil is of value during certain stages of decay, when it influences soil structure and water relations and when it functions in holding plant food in readily available form much more effectively than does any mineral fraction of the soil. The objective should be to have a steady supply of organic matter undergoing these processes for the benefit of the growing crop. Up to the present, the policy—if it can be called a policy—has been to exhaust the supply, rather than to maintain it by regular additions according to the demands of the crops produced or the soil fertility removed. To continue very long with this practice will mean a further sharp decline in crop yields.

The level of organic-matter content to be maintained is not the same for all regions. It varies according to climate. Professor Jenny in his studies of virgin organic matter of soils (*184*) has pointed out that—

> within regions of similar moisture conditions, the organic matter content of upland, terrace, and bottom-land soil, including both prairie and timber vegetation, decreases from north to south. For each fall of 10° C. (18° F.) in annual temperature, the average organic matter content of the soil increases two or three times, provided the precipitation-evaporation ratio is kept constant.

Thus from south to north the level of organic matter in the soil becomes naturally higher. In the northern section of the Temperate Zone with its moderate rate of vegetative growth and moderate production of organic matter, the longer periods of lower temperature lessen decay and increase accumulation by carry-over from season to season. In the southern section, even though the growing season is longer and produces more vegetation, yet there is also a longer season for decay, and it proceeds at a much more rapid rate. Because the rate of decay doubles and trebles for every rise of 10° C. (18° F.) in temperature, the destruction of organic matter is more complete and there is little accumulation. Its nature, particularly its composition, is also different. It shows a narrower carbon-nitrogen ratio (*184*) and a greater resistance to further simplification.

The level of organic matter in the soil of the temperate regions rises with lower annual temperatures, and also with increased moisture. The level is also higher in grasslands than in timbered soils under equal moisture conditions. The same amount of moisture in the North with its lower temperature is more effective in bringing about an increase of soil organic matter than in the South with its higher temperature. Hence sod crops are more effective restorers of organic matter in the northern than in the southern part of the North Temperate Zone. The climate of the region must be considered in determining the level of organic matter to be maintained in the soil. Changes in altitude must also be considered insofar as these correspond to climatic variations.

In northern Missouri, for example, virgin soils are in a condition of natural equilibrium at an organic-matter content of 3.54 percent; in southern Missouri at 2.20 percent; in southern Minnesota at 4.44 percent; and in Arkansas at 1.96 percent. In terms of pounds per plowed acre, the figures are: For southern Minnesota, 88,800 pounds; northern Missouri, 70,800 pounds; southern Missouri, 44,000 pounds; and Arkansas, 39,200 pounds. These figures represent the natural equilibrium between the production of organic matter by native vegetation and its destruction by micro-organisms. The balance figure is determined in the main by the temperature-rainfall combination, or climate. It would be folly, according to these data, for the farmer in Arkansas to attempt to increase organic matter in his soil to the level common in the soil tilled by the Minnesota farmer. Likewise the problem of increasing the organic matter will be simpler for the farmer in the North, where even with the same amount of moisture, the lower temperature is influential in preserving more of the organic matter added to the soil.

Cultivation of the soil and extended periods without a vegetative cover decrease the content of organic matter below that considered natural, or virgin, for the locality. The degree of exhaustion of organic matter to levels below the virgin stock represents the possibilities of improvement. But these possibilities also are affected by climate. In the northern sections both temperature and moisture conditions are favorable to restoration, and the growing of legumes and the addition of green manure are very effective in this direction, as experimental results demonstrate. Farther south, restoration is more difficult, and it may even be impossible to restore the organic

matter profitably and permanently to levels even approaching virgin conditions. However, the longer growing season permits two crops a year, one of which may be a legume for green manure, and this makes it possible to provide organic matter and a turn-over of nitrogen regularly even when the level cannot be raised.

We are confronted, then, by three facts: (1) The stock of organic matter in the soil is being exhausted at an alarming rate; (2) the exhaustion is still in its early stages in some of the more recently developed agricultural areas; and (3) there are no climatic handicaps that prohibit restoration. These facts mean corresponding—and inescapable—responsibilities. The Nation should be made aware of the rapid rate at which the organic matter in the soil is being exhausted. Farm-management practices should be adopted that will at least maintain, and in as many cases as possible even increase, the supply of this natural resource in the soil. The maintenance of soil organic matter might well be considered a national responsibility.

INTERRELATION OF SOIL ORGANIC MATTER WITH NITROGEN AND MINERALS

At first thought, the problem of restoring soil organic matter may not seem difficult according to simple mathematical calculations. If a soil in virgin condition contained 44,000 pounds of organic matter per acre and 35 percent of this has been exhausted during 60 years of cultivation, the apparently simple solution would be to add 15,400 pounds of dry material to the soil, or an amount of organic matter equivalent to the weight lost. The addition of the equivalent of some 7¾ tons of dry matter in the form of manure, legumes, straw, and other farm-waste products might seem to be a satisfactory solution. But the virgin organic matter that has been lost was very different in nature and effects from the material considered to replace it. In kind and composition, the organic matter used for restoration should be as close as possible to that which was lost, at least in terms of effective results.

Building Soil Organic Matter Largely a Nitrogen Problem

Soil bacteria, the agents of decomposition, use carbon mainly as fuel and nitrogen as building material for their bodies and for the production of the intricate organic compounds that result from their activity. Fresh organic matter is characterized as a rule by a large amount of carbon in relation to nitrogen. It has a wide carbon-nitrogen ratio, in other words; or so far as the bacteria are concerned, a wide ratio of fuel to building material. Such fresh material—straw, for example—may have a ratio that is too wide, so that it decomposes very slowly. If the ratio is less wide, decomposition may be more actively carried on. The carbon will then be rapidly used up as fuel while the nitrogen is held or treasured without appreciable loss.

Thus when decay has proceeded to the point where the carbon-nitrogen ratio is significantly decreased, a residue of a more stable nature is produced. Thereafter the carbon-nitrogen ratio is narrower and remains more constant. This corresponds more nearly to the

condition that holds in the case of the organic matter in virgin soils. Its further decay, which is slow because of the relatively low level of carbon, liberates nitrogen in place of storing or preserving it. Because of its high carbon content, the decomposition of fresh organic matter requires additional soluble nitrogen to be used as building material by the micro-organisms, which obtain it from the soil, often exhausting the supply to a degree that is damaging to a growing crop. The amount of increase in organic material corresponds, in the main, to the amount of nitrogen available. The extra carbon in the fresh material is lost from the soil. Thus when soils are given straws, fodders, and similar crop residues of low nitrogen content, only small increases in soil organic matter can result—in the main, only as large as the added nitrogen will permit. Many tons of common farm residues and wastes per acre are needed to produce a single additional ton of organic matter in the soil.

The restoration of soil organic matter, then, is a problem of increasing the nitrogen level or of using nitrogen as a means of holding the carbon and other materials. This is the basic principle behind the use of legumes as green manures. In building up the organic content of the soil itself, it will often be desirable to use legumes and grasses rather than to add organic matter, such as straw and compost, directly. If legumes and grasses are to be successfully grown on many of the soils of the humid regions of this country it will be necessary, first, to properly fertilize and lime the soil. Legumes use nitrogen from the air instead of the soil, and thus serve to increase the amount in the soil when their own remains are added to it. Commercial nitrogen used as treatment on straw for the production of artificial manure in compost piles, or when plowing under straw in the field after the combine, may be considered in the same category. Small amounts of added nitrogen may in this way make possible the use of large amounts of carbonaceous matter in restoring the soil. Thus the European farmer first "makes" his manure by composting the fresh straw-dung mixture from the barn and then treats it intermittently with the nitrogen-bearing liquid manure or urine from the same source and the nitrogen-rich leachings from the manure pit. He does not consider the fresh, strawy barn waste manure in the strictest sense until the surplus carbon has been removed through the heating process, and the less active manure compounds become similar to those of the soil organic matter. In a similar way, it should be understood that the soil organic matter can be "made" or built up only as the nitrogen supply is raised and combined with carbonaceous material in a more narrow ratio.

It is only under conditions of this kind that beneficial effects on crops may be expected through further decomposition. The manure making of the Old World farmer turns the miscellaneous straw-dung-urine mixture, of highly variable value, into a standardized fertilizer for specific use. Our great variety of crop wastes—straw, cornstalks, etc.—should be used in a similar way, by adding nitrogen to bring about a proper adjustment with their excess carbon. These neglected wastes will then provide extra and valuable soil organic matter that will have beneficial rather than possibly detrimental effects on crops.

Level of Minerals in Soil Influences Organic-Matter Supply

Bacterial activity does not occur in the absence of the mineral elements, such as calcium, magnesium, potassium, phosphorus, and others. These, as well as the nitrogen, are important. Recent studies show that the rate of decomposition is reduced when the soil is deficient in these elements. In virgin soils high in organic matter, these elements also are at a high level, and are reduced in available forms as the organic matter is exhausted. A decline in one is accompanied by a decline in the other.

It has been held that calcium, for example, is instrumental in retaining the organic matter in a stable form in the soil. Though this seems doubtful in view of the fact that the addition of lime to soils hastens the rate of loss of organic matter, calcium has a decided influence on the growing crop and therefore on the amount of material it adds to the soil when turned under. It has recently been discovered that the fixation of nitrogen from the atmosphere by legumes is more effective where high levels of calcium are present in available form (*3*). Thus, if in calcium-laden soils, excellent legume growth results and correspondingly large nitrogen additions are made, such soils may be expected to contain much organic matter. Liberal calcium supplies and liberal stocks of organic matter are inseparable. The restoration of the exhausted lime supply exerts an influence on building up the supply of organic matter in ways other than those commonly attributed to liming.

In the presence of lime (calcium) the legumes use other elements more effectively, such as phosphorus (*175*) and probably other nutrients. Thus heavier production results on soils rich in minerals, including more intensive and extensive root development—the most effective means of introducing organic matter into the soil. The presence of large supplies of both organic matter and minerals points clearly to the fact that the soils were high in the latter when the former was produced. It seems logical to ascribe causal significance to the minerals in the production of organic matter, whether or not they are effective in preserving it. If the soils that have lost their organic matter are to be restored, the loss of minerals, which has probably been fully as great, must be taken into account, and provision must be made to restore these mineral deficiencies before attempting to grow crops for the sake of adding organic matter.

HOW CAN SOIL ORGANIC MATTER BE RESTORED?

Conservation and restoration of soil organic matter as a national problem calls for a program of soil and farm management in which (1) needless losses are eliminated or reduced to a minimum, and (2) the stock in process of consumption is regularly maintained with attention to its possible economical increase. Experimental results indicate the steps in such a program.

First attention should be given to eliminating accelerated erosion. When, according to the long-continued soil erosion studies at the Missouri Agricultural Experiment Station (*263*), the entire plowed surface soil under continuous corn may be washed away in 50 years, it would be foolhardiness to attempt soil building by processes so

slow as to make only an inch in hundreds of years. Erosion can be eliminated, as the investigations have shown and recent extensive erosion-control experience demonstrates, by sod cover crops, reduction in the amount of tillage, and other measures. The establishment of sod crops on badly eroded land often requires proper fertilization and liming.

Sod crops have not been fully appreciated. Grasses have been the stepchildren in the American crop family. They have not been "cultivated" in the same sense as farm crops; they have been left to themselves, to grow on soils often turned over to them because depleted fertility made cereal cropping unprofitable. They have been incidental in the farm program. Consequently, they have not delivered their maximum in animal production and have often been very inefficient feed. Land in grass was considered idle and checked off the accounts, even if not recorded on the debit side.

The Old World, with its longer agricultural experience, shows that the lands still in good production today are those occupied by sod crops regularly for a large part of the time, where clean, or summer, cultivation has been reduced to a minimum. In France and England only slightly more than one-fourth of the cultivated soils are in clean cultivation. In Germany the figure is even less, and there are vast acreages of permanent pastures in all these countries. In the United States the area in clean cultivation and row crops approaches one-half the cultivated land; and this in regions where the rains are of torrential nature. We may well be guided by Old World experience, which tells us that sod crops are a paramount factor in holding the soil and maintaining its productivity by their regular additions of organic matter. The tough sod slice should be more fully appreciated as an asset in terms of its organic matter rather than considered as a liability because of the high power required to plow it.

Some recent studies suggest that we have not appreciated sod crops in relation to moisture absorption and the storage of moisture in the subsoil. The beneficial effects of sods turned under for corn crops have usually been ascribed to nitrogen, when possibly the important factor has been accumulated moisture in the subsoil. Grass crops absorbed 87.4 percent of the rainfall, a 3-year rotation with one sod crop absorbed 85.5 percent, while continuous corn absorbed only 69.6 percent, according to trials extending over 14 years (*263*). This amounted to an increased rainfall of 7.2 inches for grass and 6.4 inches for rotation as compared to continuous corn. The difference in crop yield was more significant than these figures indicate, since two-thirds of the annual rainfall came in the 6 months of the growing season, or the period when differences in rainfall mean increased yields.

Much of the extra water absorbed moves beyond the zone of consumption by the shallow grass roots and is stored there. Thus the deeper soil layer under sod, such as the third foot, carries more water than the same layer under tilled soil. Moisture studies of two such adjacent soils, not far distant from those under the erosion study cited above, are interesting from this standpoint, especially for the years 1934 and 1936, which were seasons of deficient rainfall. Table 1

gives the moisture content as the percentage of moisture in the successive 1-foot layers to a depth of 3 feet.

The third-foot layer was much drier under the tilled soil than under the sod during all of these studies. Its recovery of moisture after rain was always delayed and its total water content never equaled that in the third foot under sod. Though the first-foot layer under sod had a lower moisture content than that under tillage during 1

Table 1.—*Moisture content at successive depths under sod and under cultivated soil*

Year and month	First foot		Second foot		Third foot	
	Sod	Tilled	Sod	Tilled	Sod	Tilled
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1934:						
April	27.18	25.23	29.90	24.61	26.11	16.58
November	32.80	31.70	31.90	30.80	32.60	24.80
1936:						
March	26.30	27.80	28.20	28.90	28.30	23.00
November	27.00	26.80	28.50	27.30	27.80	19.80
1937:						
April	32.90	28.30	30.00	28.60	30.70	23.40

month (March 1936), in all samplings the moisture supply of the second- and third-foot layers was greater under the sod than under the tilled surface, with the most pronounced differences in the third foot, varying from 5.3 to 9.5 percent. These differences mean on the average that the third-foot layer under sod is storing the equivalent of a 1.2-inch rainfall, which it may supply to the sod crop, or to the deeper roots of the following crop, in the drier summer season. This stored moisture under sod should be considered as a factor in combating droughts.

The advantages of grass-sod crops as effective agencies for soil restoration may be summed up as follows: They do much toward guaranteeing a moisture supply for their own needs by absorbing more of the rainfall. They add a heavy root growth annually that, for native bluestem, for example, amounts to as much as 1.34 tons per surface acre-foot, according to Weaver and Harman (*453*). Because of the annual death of part of these roots, this is a regular addition of organic matter that helps to maintain the supply. On the untilled and less violently aerated soil, where the higher moisture means lower temperatures, these conditions favor a return to the original, or virgin, stock of organic matter in the soil. At the same time, erosion is prevented both by the living grass and by the spongy surface residue accumulated above the soil from the dead plant tops of the previous season.

Sod crops are sufficiently effective in restoring soil organic matter to offset the destructive influences of clean cultivation and summer tillage. Unpublished data from studies by the Missouri Agricultural Experiment Station show clearly the destructive influence of summer fallow and, in contrast, the increase in organic matter obtained through sod crops. When sod was used in an ordinary 3-year crop rotation, with manure made from the crops returned to the soil, there was no serious decline in the content of organic matter, as shown by table 2.

Table 2.—*Gains and losses in soil organic matter (in pounds per acre of surface soil) during 17 years, on areas under different systems of cropping and management* [1]

Crop and management	Gain	Loss
	Pounds	*Pounds*
Rotation—corn, wheat, clover—all crops removed		800
Rotation—corn, wheat, clover—manure equivalent returned	3,200	
Rye and cowpeas—turned under as green manure	1,200	
Rye turned under—summer fallow		14,400
Red clover continuously—all crops removed	3,600	
Red clover continuously—all crops turned under	9,600	
Alfalfa continuously—all crops removed	10,400	
Grass sod, clipped—nothing removed	10,000	

[1] Unpublished data of M. F. Miller, Missouri Agricultural Experiment Station.

The provision of liberal supplies of soluble plant nutrients for profitable cereal production demands tillage and the breaking down of organic matter. The organic matter to be broken down should be provided by sod crops, particularly legumes, used regularly in the rotation. Permanent legume sods are effective agents, as this study testifies, in building up the organic matter on soil containing ample minerals, particularly when the crops are not removed. Continuous red clover sod with no crop removal increased the organic-matter content by a total of 9,600 pounds in 17 years, or an average of 564 pounds a year. In similar soil in another plot nearby that was given 2½ tons of clover annually as a green manure under fallow, the annual gain in organic matter amounted to 571 pounds a year (see fig. 3).

NEW AWARENESS AND NEW RESPONSIBILITY

American citizens are becoming conscious of the fact that loss of fertility and the depletion of organic matter in the soil are partly responsible for the menace of erosion. The first step in remedying this situation is to restore fertility by the use of lime and fertilizer. The second step is to put some lands permanently into sod crops—legumes wherever possible, and the better grasses—and to use sod more regularly in rotations on tillable cropped lands. The conservation and use of such farm wastes as crop residues and manures should be included as the third step.

If these practices are recommended as proper soil management by all agricultural agencies, their adoption by individual farmers will become so common that the rate of soil depletion will be lessened. The need for long-time investments in materials that build up the soil in organic matter and fertility should be recognized in granting credit to farmers. Both owners and tenants must accept responsibility for soil conservation and work for it cooperatively. Unearned increment, the great wealth producer of the past, should be recognized as largely responsible for the mining of soil fertility and the burning up of soil organic matter until it has reached such a low level that this source of wealth has an extremely uncertain outlook in the future. The heritage of soil fertility and organic matter that we are handing on to the next generation is not large enough to be used lavishly. Careful conservation and thrifty management will be imperative if it is to yield even a moderate income.

NITROGEN is essential to plants because it plays a fundamental part in the formation of the proteins that are the stuff of living protoplasm. At the same time it is an expensive fertilizer element and one very easily lost from the soil. Where does it come from and how does it get into the soil in the first place? Under what conditions does the supply in the soil become depleted? What are the forms of nitrogen useful to plants, and what changes do they undergo? Besides considering such questions as these, the authors make a rough inventory of the amount of nitrogen existing in various great groups of soils in the United States under natural conditions.

Soil Nitrogen

By OSWALD SCHREINER *and* B. E. BROWN [1]

NITROGEN is absolutely essential to the maintenance of soil fertility. This element is so necessary to the growth and reproduction of both plants and animals that all life would cease to exist without it. Soil nitrogen is important from both an agronomic and a commercial viewpoint. The higher cost of fertilizer nitrogen; the many combinations into which nitrogen enters; the many transformations, both chemical and bacterial, that nitrogen, particularly organic nitrogen undergoes; the ease with which available inorganic nitrogen compounds may be lost from the soil through leaching, erosion, crop removal, etc.; the relatively low content of total nitrogen in most soils, of which only an insignificant, but nevertheless highly important, part is in a form available to plants; and the importance of this available nitrogen in the synthesis of complex organic substances, such as the essential proteins—these are some of the reasons why nitrogen is so important.[2]

GENERAL ROLE OF NITROGEN IN LIFE PROCESSES

In combination with carbon, hydrogen, oxygen, and occasionally other elements, nitrogen forms an essential constituent of all plant and animal tissues and plays a major role in the development and functions of protoplasm in plant and animal structures. Nitrogen is found especially in tissues that are concerned in growth and reproduction. There is evidence at hand to show that the rate of growth of plants is more dependent upon nitrogen than upon any other element. In

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[2] Other phases of the nitrogen question are discussed in articles in this Yearbook as follows: Soil Organic Matter and Soil Humus, p. 929; Fauna and Flora of the Soil, p. 940; Crop Rotation, p. 406; Some Relationships of Soil to Plant and Animal Nutrition, p. 777; and three articles on fertilizers, pp. 469 to 545.

its combined form nitrogen is universally distributed in animals and plants in albuminoid or protein substances, such as the casein of milk or the gluten of wheat. The vital importance of nitrogen may be further appreciated when it is considered that without nitrogen there can be no growth or reproduction on the part of plants or animals.

PRIMARY SOURCE OF SOIL NITROGEN

The mineral compounds of the soil, like calcium, magnesium, silicon, and iron compounds, originated from the decomposition of original rock material, but insofar as nitrogen compounds in the soil are concerned, the nitrogen they contain was derived from the air. The air is primarily a mixture of nitrogen and oxygen gases of which about 80 percent by volume consists of nitrogen in a free or uncombined state. It has been estimated that over every acre of land surface there are about 145,000 to 150,000 tons of this free nitrogen. Plants, however, are unable to avail themselves directly of this immense supply of raw material. Before they can do so the element has to enter a state of combination with other elements. The chief difficulty in this is that nitrogen is very inert and very stubbornly opposed to entering into combination with other elements. Only through the intervention of powerful influences, such as lightning discharges or very powerful chemical reactions on the one hand, or through the milder but just as effective influence of soil bacteria on the other, can nitrogen be "fixed" with other elements. The importance of atmospheric nitrogen as a raw material to supply agricultural and industrial nitrogen needs cannot be too highly stressed or appreciated.

THE NITROGEN CYCLE

As the products of plants or the plants themselves are utilized by animals, still further utilization of combined nitrogen is effected. Complex protein compounds are built up for the animal tissues, blood, etc., but some of the nitrogen in the food consumed is voided as waste with a resultant break-down of the complex nitrogen compounds originally in the food. When plants and animals die and their bodies decay, nitrogen is released from the complex combinations either as free nitrogen or as ammonia, a compound of nitrogen and hydrogen. Thus there is a continuous cycle going on of building, tearing down, and rebuilding. Animals have no means of utilizing free nitrogen or even the simple nitrogen compounds of an inorganic nature. Because plants have the ability to synthesize simple inorganic compounds into complex proteins, animals are dependent upon plants for their sustenance, either directly or indirectly through the consumption of the products of other animals whose existence in turn depended in some measure upon plant products.

In figure 1 is given a diagrammatic presentation of such a nitrogen cycle as illustrated by Blair (*36*),[3] who makes the following explanatory statement:

> Nitrogen is taken from the air artificially or through the agency of microscopic organisms living in association with leguminous plants, or by organisms not associated with plants. As plants, or plant residues, it is introduced into the soil as organic nitrogen. Through decomposition of the organic matter a part

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

of this nitrogen may be returned to the air as gaseous nitrogen or as ammonia, a part is converted into ammonia and nitrites, and finally into nitrates which are used by plants or lost in drainage waters, and a part remains in the soil for a long time as inert organic matter.

If the plants are used as food for animals a part of the nitrogen is recovered as manure and by-products of the slaughter house. When these are added to the soil, decomposition goes forward, as in the case of the plants or plant residues, and thus the cycle is completed.

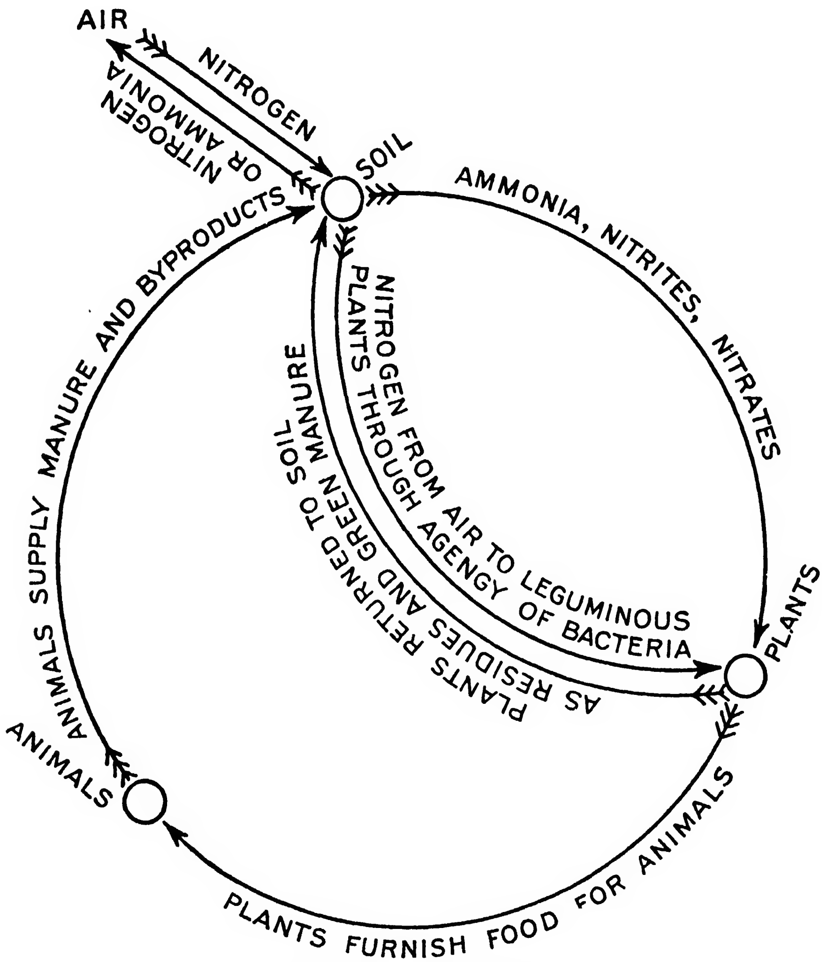

Figure 1.—The nitrogen cycle.

HOW NITROGEN GETS INTO THE SOIL

As has been pointed out, the primary source of soil nitrogen is the free nitrogen of the air, which is fixed by two kinds of processes—natural and artificial. Lightning discharges unite nitrogen and oxygen to form oxides of nitrogen. These unite with moisture in the air to form either nitrous or nitric acid which is washed out of

the atmosphere by rain or snow and enters the soil. In addition a small amount of ammoniacal and organic nitrogen gets into the soil from the atmosphere where these forms of nitrogen occur as impurities from dust and gaseous contaminations. Even at best, however, the aggregate amount of fixed nitrogen derived from the atmosphere in such a way is relatively small. It has been estimated that a total of 5 to 7 pounds of nitrogen per acre annually is added to the soil in this way. The amounts brought down fluctuate widely with seasonal conditions and proximity to factories and cities, being greater near factory towns and cities than in the open country. Table 1 shows the amounts of nitrogen brought down in rain as ammoniacal and nitrate nitrogen in different parts of the world (*226, p. 299*).

Table 1.—*Amounts of nitrogen brought down in rain*

Location	Years of record	Rainfall	Nitrogen added per acre per year	
			Ammoniacal nitrogen	Nitrate nitrogen
	Number	*Inches*	*Pounds*	*Pounds*
Harpenden, England	28	28.8	2.64	1.33
Garford, England	3	26.9	6.43	1.93
Flahult, Sweden	1	32.5	3.32	1.30
Groningen, Netherlands		27.6	4.54	1.46
Bloemfontein and Durban, South Africa	2		4.02	1.39
Ottawa, Canada	10	23.4	4.42	2.16
Ithaca, N. Y.	11	29.5	7.10	.80

These results amply confirm the statement that the amount of nitrogen accruing to the soil from the atmosphere in rain and snow is comparatively small and would by no means take care of the nitrogen requirements of growing crops.

While plants such as corn, wheat, or cotton cannot directly utilize the uncombined nitrogen of the air, there are various micro-organisms inhabiting the soil that in their life function extract elemental nitrogen from the air and transform it into fixed-nitrogen compounds essential to plants. In addition to such bacteria, known as nonsymbiotic, there are other kinds of bacteria that in association with the roots of leguminous plants—alfalfa, clover, vetch, peas, beans, etc.—fix the free nitrogen of the air in combined forms which the plant utilizes in its growth processes. These phenomena account for the greatest supply of fixed nitrogen available to plants. The quantity of atmospheric nitrogen fixed by the nonsymbiotic organisms, though varying widely with seasonal conditions and the character of the soil, averages about 25 pounds per acre annually, while the amount of nitrogen fixed by legume bacteria will average about 80 pounds per acre annually, although higher quantities have been reported. According to Lipman (*220*), the total annual addition of nitrogen to cultivated soils from the growth of legumes and associated nitrogen-fixing organisms in the United States amounts to 1,750,000 tons of this element.

Another source of addition of nitrogen to the soil is barnyard manure resulting from the feeding of animals on the farm. In recent years,

owing to the ever-increasing use of tractor power, this supply of nitrogen has diminished. The nitrogen content of manure varies widely with the kind and age of animal, the feed consumed, and other factors. In general the average content per ton of manure from animals for all conditions is taken as approximately 10 pounds. The value of manure does not rest entirely on its nitrogen content, as it also contains valuable organic matter as well as small percentages of phosphorus and potassium.

The so-called artificial fixation of atmospheric nitrogen refers to the efforts of man to accomplish what lightning and soil bacteria do, namely, to bring the free nitrogen of the atmosphere into combination with other elements. Scientific and engineering advances have brought about a tremendous change in the last 25 to 30 years in the relative importance of nitrogen sources dependent upon chemical

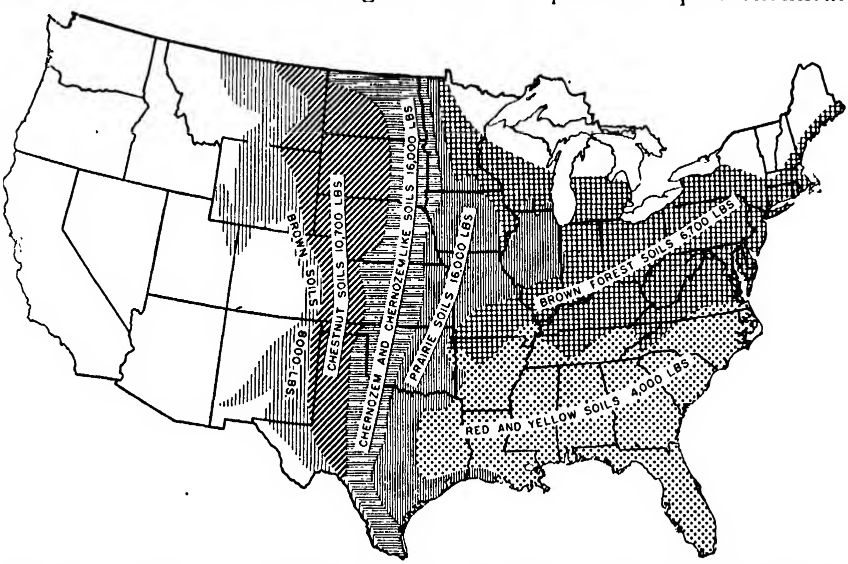

FIGURE 2.—Outline map showing average number of pounds of nitrogen per acre in various soil regions of the United States to a depth of 40 inches. White areas represent soils the nitrogen content of which has not yet been estimated in this manner.

production. In 1900 about two-thirds of the world's nitrogen supply was obtained from Chile and the rest from the manufacture of coke and gas. Thirty-four years later, according to Chemical Nitrogen, recently issued by the United States Tariff Commission (*437*), 74½ percent of the world's needed supply of nitrogen was being obtained from the air, with less than 7 percent coming from the nitrate deposits in Chile.

NITROGEN DISTRIBUTION IN SOILS OF THE UNITED STATES UNDER NATURAL CONDITIONS

The best information on the nitrogen content of soils in the United States is given by Marbut (*238*), who considered the analyses of 250 to 300 samples of soils carefully collected from selected areas under

natural conditions throughout the United States, principally east of the Rocky Mountains. These samples are from six natural soil groups, and the nitrogen content to the depth of 40 inches has been calculated. This depth has been taken as representing approximately the depth to which plants would be expected to feed and draw upon the plant-food supply of the soil.

An outline map of these large soil groups of the United States showing the approximate extent and the average content of nitrogen per acre to a depth of 40 inches in the respective regions is given in figure 2.

Naturally each region contains soils that are high and soils that are low in nitrogen, and such figures can only approximate an average content over the regions, but the differences in these larger soil groups are nevertheless very interesting and furnish the best available picture of the amount of nitrogen in the soils of the United States. Table 2 gives a summation of these figures for the various regions outlined.

Table 2.—*Average nitrogen content in various soil regions of the United States*[1]

Soil region	Approximate area of region	Approximate nitrogen in surface 6 inches	Average nitrogen to depth of 40 inches	Average amount of nitrogen per acre to depth of 40 inches
	Acres	*Percent*	*Percent*	*Pounds*
Brown Forest	180,000,000	0.05–0.20	0.05	6,700
Red and Yellow	150,000,000	.05– .15	.03	4,000
Prairie	113,000,000	.10– .25	.12	16,000
Chernozem and Chernozemlike	123,000,000	.15– .30	.12	16,000
Chestnut	102,000,000	.10– .20	.08	10,700
Brown	52,000,000	.10– .15	.06	8,000

[1] Computed from data in Marbut (*238*).

The first region is that occupying the northeastern section of the United States and comprising the States of Pennsylvania, Ohio, Indiana, Kentucky, West Virginia, Virginia, Maryland, Delaware, the southern half of New York, Michigan, and Wisconsin, a little of New England, Tennessee, Arkansas, Missouri, Illinois, Iowa, and Minnesota.

The second group encompasses the Red and Yellow soils of the South Atlantic and Gulf States, extending well into Texas, and includes most of North Carolina, Tennessee, Arkansas, and Louisiana, all of Mississippi, Alabama, Georgia, Florida, and South Carolina, and part of Texas—essentially the old Cotton Belt. The average nitrogen content of this region is about 0.03 percent.

The third region comprises the Prairie soils, covering about one-third of Minnesota, most of Iowa, the northwestern two-thirds of Missouri, the northern two-thirds of Illinois, the eastern third of Nebraska, the eastern half of Oklahoma, and about two-fifths of Texas. These soils contain on an average about 0.12 percent of nitrogen. These are the rich Prairie soils, including the black Corn Belt soils.

The fourth region is a strip parallel to the Prairie soils and extending north and south through the Dakotas, taking in the eastern two-thirds of North Dakota, the eastern third of South Dakota, the eastern half of Nebraska, a little over half of the central part of Kansas and Oklahoma, and a strip down through the center of Texas, comprising about a fifth of the total area of Texas. These Chernozem and Chernozemlike soils have practically the same nitrogen content as the Prairie soils.

The fifth area lies west of the last two groups and has a somewhat lower rainfall than the fourth group and much lower than the Prairie soils of the third group. These soils are known as the Chestnut soils. The States involved in this area are the eastern fifth of Montana, the southwestern two-fifths of North Dakota, the western three-fifths of South Dakota, the western half of Nebraska, the eastern quarter of Wyoming, the eastern fourth of Colorado, the western eighth of Kansas, a small section in the Panhandle of Oklahoma, about one-eighth of northwestern Texas, and less than one-eighth of eastern New Mexico.

The sixth group of soils are the Brown soils, just west of the Chestnut soil area, extending, like the latter, north and south. This group comprises a strip through the approximate center of Montana, down through Wyoming, covering about three-quarters of the State; a narrow strip through eastern Colorado; approximately one-half of New Mexico; and about one-eighth of western Texas. This Brown group of grassland soils showed an average of 0.06 percent of nitrogen.

Information regarding nitrogen in the other soil groups of the extreme northeastern section and the Pacific slopes is not yet available; further study is necessary. The significant generalization to be obtained from this study of the nitrogen distribution in the natural soils of the United States is that this nitrogen supply is highest in the soils of the Prairie and Chernozem regions of the central band of the United States, where it amounts to 16,000 pounds per acre to a depth of 40 inches, and then declines eastward and westward as the other soil groups are approached.

RELATION OF TEMPERATURE TO THE AMOUNT OF NITROGEN IN SOILS

In the United States the percentage of nitrogen in soils varies within wide limits from 0.01 to 1 percent or higher, the mean annual temperature varies from 32° to 72° F., and humidity factors also vary widely.

It is generally agreed that the distribution of nitrogen in soils is closely related to climatic conditions. Jenny (*183*), working essentially with the central belt of soils referred to above as the Prairie and Chernozem groups, which have developed under semihumid and semiarid conditions, respectively, has examined statistically the nitrogen content of a very large number of surface-soil samples (6 to 7 inches deep), as reported by Canadian and State experiment stations. A total of 348 soil samples were used in this study. He concluded that the total nitrogen content of the soil decreases in the United States from north to south and that this change is a negative exponential function, so that for every 18° F. fall in mean annual temperature the average nitrogen content of the soil increases two to three times.

This trend is well illustrated in figure 3 (*183*), which shows that from the high nitrogen content of northern soils there is a decline southward through the semihumid regions of Minnesota, the Dakotas, Iowa, Missouri, Arkansas, and Louisiana. Similarly figure 4 (*183*) shows this same decided trend from Canada southward to Texas in the semiarid region through the Dakotas, Nebraska, Kansas, and Texas.

These facts show why it is possible to build up the nitrogen content of northern soils by the addition of organic matter, as the low temperatures favor its preservation. Conversely, in the South it is rather difficult to increase the nitrogen content permanently by green-manuring practices, because the high temperatures favor decomposition, and nitrogen in the soil does not accumulate to the same extent as in the more northern soils.

Under natural soil conditions, before the lands are plowed, an equilibrium exists between the formation of organic matter by vegetation and its decomposition by micro-organisms, the balance being determined primarily by climatic conditions; so that under natural conditions the nitrogen content of a soil is fairly constant. But cultivation disturbs this natural equilibrium and results in a decrease of the nitrogen content, because less organic matter is returned to the soil and its decomposition is hastened by farming operations. In the wheat-growing regions this loss is approximately 20 to 40 percent of the original nitrogen in the natural soil, after a period of from 20 to 40 years. Figure 5, taken from a bulletin on soil fertility from the Missouri Agricultural Experiment Station (*185*), shows this general trend in the loss of nitrogen with years of cultivation under common farming practices in the Middle West.

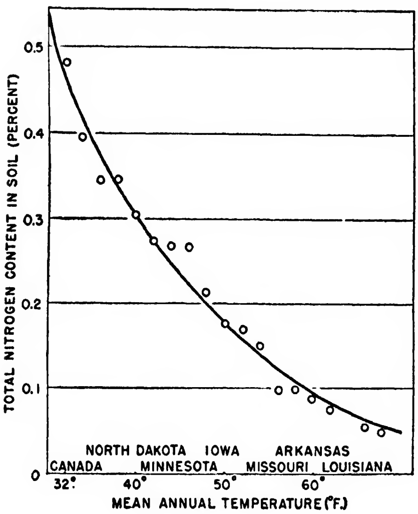

FIGURE 3.—Decline of nitrogen content in soils with rise in mean annual temperature in the semihumid region.

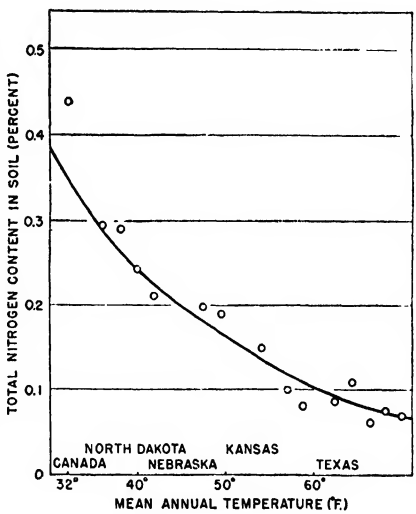

FIGURE 4.—Decline of nitrogen content in soils with rise in mean annual temperature in the semiarid region.

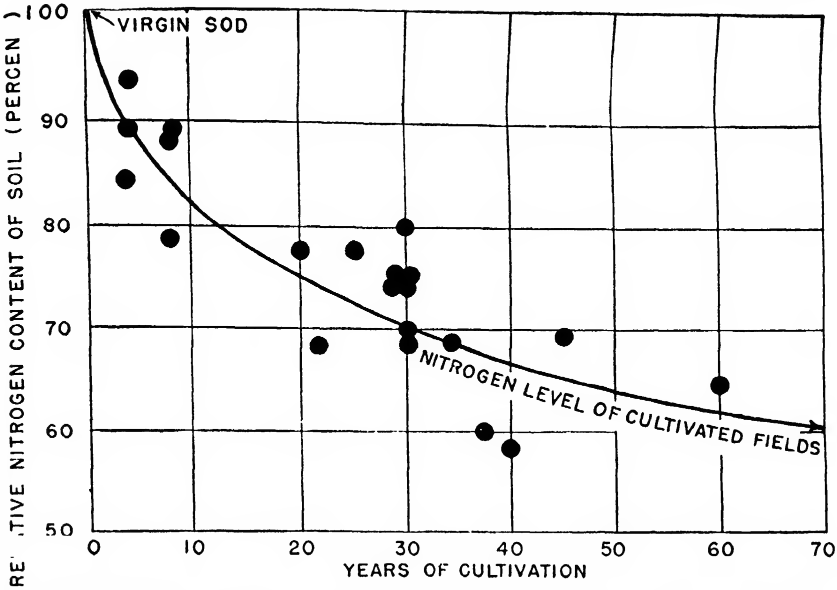

FIGURE 5.—Decline of nitrogen content in soils with length of cultivation periods under average farming practices in the Middle West.

The loss is most rapid in the first 20 years, when it amounts to approximately 25 percent of the original quantity under natural conditions; a 10-percent further loss occurs during the second 20 years, and a 7-percent loss during the third 20 years, indicating that the nitrogen level does not decline indefinitely and that the end result will be a new equilibrium at a decidedly lower level than the original natural nitrogen content. That these losses can be controlled and soil fertility maintained at a higher level by appropriate rotations, manuring, and fertilizing is shown in other articles in the Yearbook.

As a result of growing wheat on the same land for 12 years Snyder (*372*) in Minnesota showed that the nitrogen had been reduced 2,039 pounds, or about 26 percent of that originally found in the soil at the beginning of the test. The crops grown, however, accounted for less than 450 pounds of this nitrogen, showing that nearly 1,600 pounds had been lost, mainly through decay of the soil organic matter under this type of continuous farming. In Illinois a plot on which corn was grown for 16 years contained 4,000 pounds and adjoining pasture land 4,914 pounds of nitrogen in the surface soil, according to Hopkins (*169*). The Pennsylvania long-term experiments (*456, p. 202*) furnish a further example in that the untreated plots decreased in nitrogen from 0.124 percent in 1899 to 0.111 percent in 1921.

DISTRIBUTION OF NITROGEN IN SOILS ACCORDING TO DEPTH

As a general rule, the content of nitrogen in soils is greatest in the plow level and decreases with depth, which is also true of soil organic

matter. Analytical figures showing the distribution of nitrogen according to depth as given by Hopkins (from Bear (*25, p. 55*)) are presented in table 3.

Table 3.—*Quantity of nitrogen in an acre of soil*[1]

Soil type[2]	0–6⅔ inches	6⅔–20 inches	20–40 inches	0–40 inches
	Pounds	*Pounds*	*Pounds*	*Pounds*
Deep peats	34,880	64,980	97,730	197,590
Black clay loams	7,230	7,470	3,210	17,910
Brown silt loams	5,035	5,920	3,570	14,520
Brown loams	4,720	6,660	4,150	15,530
Deep gray silt loams	3,620	2,250	2,280	8,150
Brown sandy loams	3,070	3,920	4,160	11,150
Yellow-gray silt loams	2,890	2,710	3,240	8,840
Gray silt loams	2,880	3,210	3,240	9,330
Drab silt loams	2,800	3,160	3,400	9,360
Yellow fine sandy loams	2,170	2,610	2,730	7,510
Yellow silt loams	2,020	2,050	2,410	6,490
Light-gray silt loams	1,890	1,920	2,100	5,910
Sands	1,440	2,070	3,100	6,610

[1] 6⅔ inches of topsoil is represented to weigh 2,000,000 pounds.
[2] Types found in considerable areas in the North Central States.

NITROGEN AN IMPORTANT FACTOR IN MAINTAINING SOIL FERTILITY

The presence in the soil of an adequate supply of available nitrogen is one of the most important factors relating to the maintenance or improvement of soil fertility. The lack of sufficient amounts of available nitrogen in soils, particularly those that have been cropped for many years, has long been a limiting factor in crop production. A deficiency of available nitrogen results in plants of poor color and appearance, poor quality, and low production. A sufficient supply of available nitrogen, on the other hand, is largely instrumental in getting plants off to a quick start and has a subsequent tendency to encourage stem and leaf development. Such plants will make a more rapid, thrifty growth and possess a normal deep-green color and generally healthy appearance. It has been shown also that plants supplied with sufficient nitrogen are much better able to utilize other nutrient materials such as phosphorus and potassium compounds. The curtailed leaf surface resulting from a lack of available nitrogen in the soil is usually reflected in a lowering of yield, since yield is ordinarily proportional to leaf development. No amount of available phosphorus and potassium will overcome a deficiency of available nitrogen; it is generally recognized that one nutrient element cannot be substituted for another. An oversupply of available nitrogen in the soil, on the other hand, tends to cause late maturity and poor seed development and to make plants more susceptible to disease organisms on account of the development of more succulent tissue, and is decidedly uneconomical because of the unnecessary use of soil nitrogen above actual plant requirements.

HOW SOIL-NITROGEN LOSSES OCCUR

From one cause or another, losses of nitrogen from soils are constantly going on. The main causes are leaching, removal by crops and ani-

mals, soil erosion, decay processes, and, under certain soil conditions, denitrification.

Leaching concerns largely the available forms of nitrogen, such as nitrates, and to some degree ammonium compounds. Nitrates are very soluble and move freely with up and down movements of soil moisture. Heavy rainfall tends to wash nitrates into lower soil depths away from the plant action. Ammonium compounds move less freely in the soil than nitrates, being more liable to fixation by certain of the soil components. Leaching of soluble nitrogen compounds is more pronounced in light sands and sandy loams than in heavier soils, especially if the subsoil is pervious to any extent. The best cultural practice that tends to offset such losses is a growing crop to utilize the available nitrogen compounds in growth processes and convert them to forms that when turned back into the soil furnish a source of organic nitrogen less subject to leaching than the original nitrates.

Crops remove large quantities of nitrogen from the soil. If the wheat, corn, or other crop grown is largely sold off the farm, just so much nitrogen goes with them. The same applies in some measure to animals when meat and milk products are sold, although this loss is offset to some extent by the manure produced. Table 4 (*454, pp. 184–185*) will show how much nitrogen certain crops take out of the soil.

Table 4.—*Nitrogen content of different harvested crops*

Crop	Acre yield	Nitrogen content per crop acre
		Pounds
Alfalfa, hay	4 tons	190
Barley:		
Grain	40 bushels	35
Straw	1 ton	12
Total		47
Cabbage	15 tons	105
Clover, red (hay)	2 tons	84
Clover, alsike (hay)	2 tons	82
Corn:		
Grain	65 bushels	60
Stalks (stover)	1.75 tons	33
Cobs	900 pounds	3
Total		96
Corn, silage	12 tons	82
Cotton:		
Lint	500 pounds	1.0
Seeds	1,000 pounds	38.5
Stalks and leaves	2,000 pounds	28.5
Total		68.0
Cowpeas, hay	2 tons	124
Oats:		
Grain	50 bushels	35.0
Straw	1.25 tons	15.0
Total		50.0
Onions, bulbs	500 bushels	60
Potatoes, tubers	200 bushels	45
Rye:		
Grain	25 bushels	26.5
Straw	1.25 tons	12.0
Total		38.5
Sugar beets.		
Roots	15 tons	78
Leaves (green)	6.2 tons	40
Total		118
Sweetpotatoes, tubers	200 bushels	35
Timothy (hay)	2 tons	40
Tobacco:		
Leaves	1,500 pounds	41
Stalks	1,250 pounds	26
Total		67
Wheat		
Grain	30 bushels	35.5
Straw	1.6 tons	16.0
Total		51.5

This shows conclusively that the crops make a heavy demand on soil nitrogen, making it essential that the farmer meet such losses in order to maintain the productivity of his soil at a high level.

Soil-erosion factors concerned in soil losses are discussed elsewhere in this Yearbook, but any actual loss of soil caused by erosion, whether from water or wind, means a serious loss of nitrogen, difficult to replace. Prevention of soil erosion will automatically conserve organic matter with its essential nitrogen.

Another factor involved in nitrogen losses is associated with the death and decay of plants and animals. During the process, losses of nitrogen, either in a free state or as ammonia, may ensue under certain conditions. The same is true of manures if improperly kept or utilized, when serious losses of nitrogen may take place by escape into the atmosphere. Poor soil conditions, as in submerged land or swampy areas, favorable to denitrifying or anaerobic organisms, may cause losses whereby nitrogen is freed from its combinations and returned to the atmosphere. Losses of this character are avoidable if the soil drainage adequately aerates the soil.

Any attempt to set up a balance sheet for nitrogen is likely to be in error by a considerable margin. At the same time such appraisals are helpful in bringing more forcibly to our attention an approximation of nitrogen income and outgo.

Lipman (*220*) has proposed certain data to indicate the status of soil nitrogen with reference to how much nitrogen is lost annually and how much is added to the soil to offset the losses. The balance sheet has been estimated as follows:

	Tons
Losses (harvested crops, grazing, erosion, leaching)	22, 899, 046
Additions (fertilizers, manures and bedding, rainfall, irrigation waters, seeds, nitrogen fixed)	16, 253, 862
Net annual loss	6, 645, 184

It is very evident that, even allowing for possible errors in these preliminary estimates, the amount of nitrogen lost from the soil is very great. This emphasizes in a striking manner the fact that the soils of the United States are suffering a steady decline in fertility. If such an enormous annual loss of nitrogen from the soil actually occurs, then the necessity of doing everything possible to conserve the nitrogen reserves of the soil is self-evident. Some of the steps to counteract such a loss would include a wider and more effective use of nitrogen-supplying leguminous crops, preservation and better utilization of farm manures, the prevention of soil erosion, the growing of cover crops to absorb available nitrogen instead of having it leached from the soil, and a cheapening of fertilizer nitrogen to encourage its greater use in fertilizer practices.

By growing a cover crop during the winter season, particularly under southern soil conditions, leaching will be decreased considerably. Greater care in maintaining the reaction of the soil at a point that would promote a heavier growth of leguminous or cover crops would help furnish more nitrogen. It would appear, however, that an important offset to any nitrogen deficit will have to come to a large extent from applications of nitrogen fertilizer materials, either as such or in mixed fertilizers.

NITROGEN FORMS UTILIZED BY PLANTS

The fairly general belief that nitrogen must be in nitrate form to be of service to plants is by no means true. This has arisen from the fact that chemical examination shows that comparatively little ammonium or nitrite compounds are present in the soil—that nitrates predominate. Moreover it is thought that ammonium compounds pass over to nitrates in relatively short order owing to bacterial action, the speed of which depends largely upon moisture supply, soil temperature, and soil reaction. The nitrites in turn are quickly converted to nitrates, the ultimate oxidation product of soil nitrogen. However, there is fairly well established evidence to show that both ammonia and organic compounds are directly utilized by plants.

With reference to the utilization of nitrites by crop plants, studies indicate that nitrites are injurious to plants although small amounts of nitrite nitrogen appear to be utilized.

Ammonia is constantly being formed in soils as the result of the action of ammonifying bacteria on soil organic matter, but the quantity present is generally not great, normally only a few parts per million of soil. It is known that rice grown on flooded lowland soils responds more markedly to applied ammonium salts than to nitrates, owing probably to the submergence, which affects the nitrates more adversly than ammonium salts. Stewart, Thomas, and Homer (*387*) drew the conclusion that pineapple plants were able to utilize all required nitrogen in the form of ammonium compounds, although under field conditions both nitrate and ammoniacal nitrogen compounds were assimilated by this plant.

Allison (*9*), working with corn in culture solutions containing various ammonium salts in comparison with nitrates, showed that under the imposed conditions there was nothing to indicate any superiority of nitrate nitrogen over ammoniacal forms. He further points out that it is possible that more ammoniacal nitrogen is utilized by higher plants than is generally supposed.

Hutchinson and Miller (*177*) have given a good review of the work done before 1911 in respect to organic forms of nitrogen assimulated by plants, and their own studies show that many organic compounds are utilized directly by higher plants. Schreiner and Skinner (*350*) tested a wide range of organic nitrogen compounds for plants, some of which proved beneficial, others harmful. The principal organic compounds utilizable by plants appear to be certain of the amino acids and other intermediate products resulting from the breaking down of protein nitrogen into relatively simple water-soluble forms of organic nitrogen. Very little is known as to the amount of organic nitrogen actually assimilated by plants, and it may be that quick conversion of the organic nitrogen to ammoniacal and to nitrate forms is a determining factor in the apparent response of plants to organic nitrogen compounds when applied to soils.

NITROGENOUS ORGANIC CONSTITUENTS OF SOILS

By far the greatest tie-up of nitrogen in the soil is in organic combinations with the soil organic matter. In this form the nitrogen is comparatively insoluble and therefore unavailable to higher plants. If

this were not so the nitrogen supply of soils would be depleted very rapidly. Soil organisms utilize this organic nitrogen and in so doing transform the complex organic nitrogen compounds into more simple compounds available to higher plants. Generally speaking, the breakdown of any organic constituent added to soils in organic materials is in the direction of complex to simpler forms. At the same time it is known that soil organisms produce complex nitrogen compounds from the simple inorganic compounds, thus furnishing another interesting cycle of nitrogen transformation in the soil itself.

In a fertile soil the organic matter, and consequently the nitrogen, is continually changing from season to season. The very life of the soil and all its fertility-promoting factors depend on this change. When organic matter has ceased to change, has become chemically and bacteriologically inert, the result is infertility. It is the changing character of the organic matter that makes for soil fertility, not the mere presence or store of organic matter in the soil.

In order to understand soil fertility as influenced by organic manures, green manures, and good farming methods study should be made not so much of the nitrogen content—except as this is a key to these dynamic factors—as of the organic chemical changes themselves. In this field of research much remains to be done, but a study of soil nitrogen compounds [4] has been in progress for some years. A diagrammatic presentation of decomposition is shown in figure 6.

Some of these nitrogenous organic soil compounds are the units obtained when one of the complex proteins, nucleoproteins, etc., is resolved into simpler compounds by chemical means. Other organic soil compounds are derived by further decomposition; by deamidization, oxidation, and reduction from amino acids, carbohydrates, and other organic compounds, with liberation of ammonia, carbon dioxide, sulphuretted hydrogen, and other final as well as intermediate soil products. The diagram will make some of these exceedingly complex and involved chemical processes as clear as is possible in a nontechnical manner.

The diagram illustrates that a complex nucleoprotein can be split into protein and nucleic acid, both of which have been found in soils. The protein can be further split into a number of smaller units, known as cleavage products of protein or primary degradation products. These units out of which the complex structure of the protein is built comprise such nitrogen compounds as histidine, arginine, lysine, and others. Those mentioned have all been found in soils, and their beneficial action on plants has been demonstrated.

This process of taking the complex nitrogen compounds apart is accomplished by fairly simple chemical means, involving chiefly the process known as hydrolysis; but to effect further decomposition of these units means more deep-seated changes and, as it were, actual breaking up of the units themselves. The diagram shows how by oxidation or reduction many of the soil compounds can arise during this process of change, and how finally the end products, ammonia, carbon dioxide, sulphuretted hydrogen, etc., are reached. In soils,

[4] Some of the nitrogenous organic constituents isolated from soils are creatinine, creatine, histidine, arginine, choline, adenine, guanine, xanthine, hypoxanthine, picoline, carboxylic acid, nucleic acid, allantoin, cyanuric acid, trimethylamine, cytosine, and chitin (*349*).

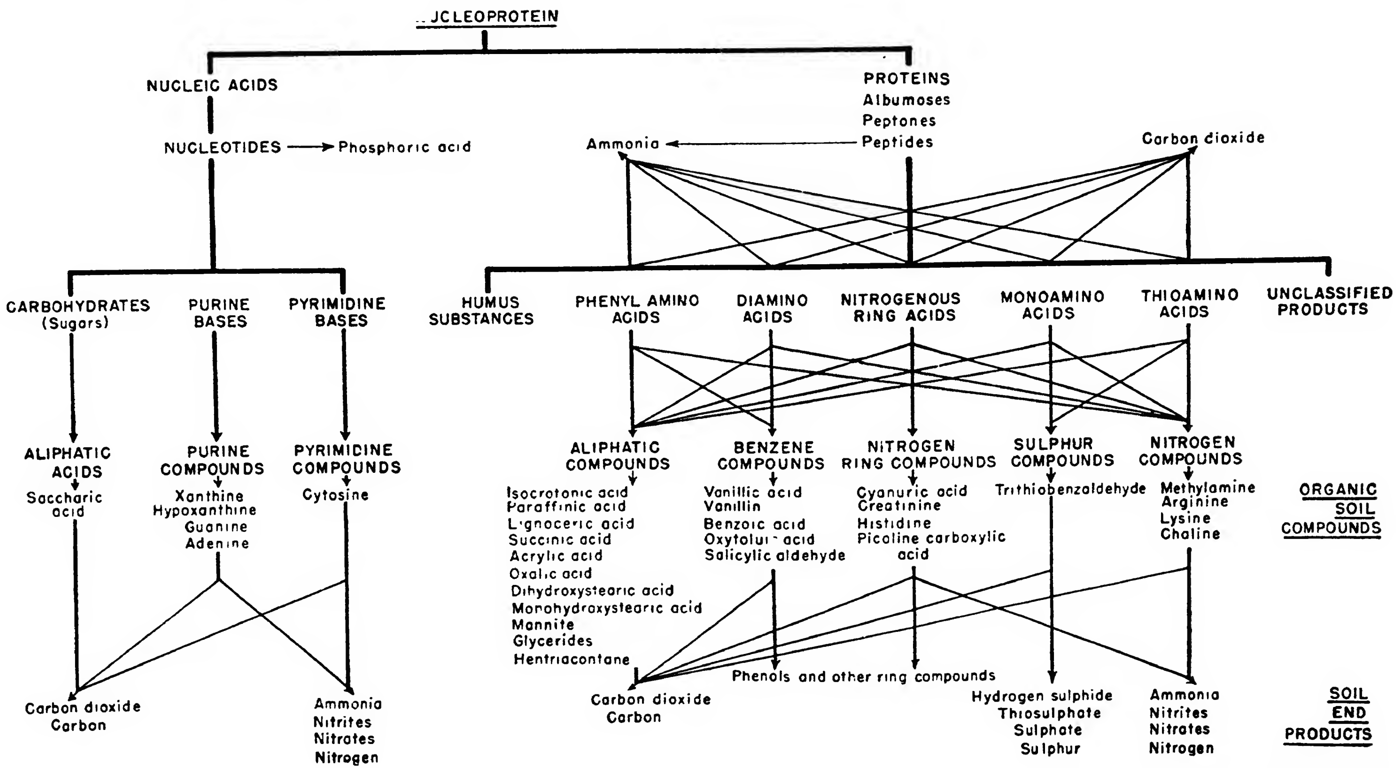

FIGURE 6.—Diagram showing the decomposition of a complex nitrogenous plant or animal product in the soil, giving rise to many intermediate substances as soil constituents and finally ammonia, nitrites, nitrates, and elementary nitrogen.

as is well known, the ammonia is again changed to nitrite and nitrate, and thus, according to most authorities, the cycle is completed and the nitrogen is ready to start again on its mission to promote plant growth.

The decomposition of the nucleic acid, which was one of the component parts of the nucleoprotein used in the illustration, can be similarly traced. Like the protein part, nucleic acid yields smaller chemical units. These units of the structure of nucleic acid comprise such compounds as hypoxanthine, xanthine, guanine, adenine, cystine, pentose sugars, phosphoric acid, and others. All those mentioned have been found in soils. Like the cleavage products of the protein these further decompose in the soil, and the nitrogen appears first as ammonia, then nitrite and nitrate, as with protein.

That nucleic acid and others of the protein-degradation products can serve directly as plant food in building up plant tissue has been shown by Schreiner and Skinner (*350*). The action of some of these compounds in promoting growth resembles in effect the growth-promoting influences of vitamins in animal nutrition or hormones in plant physiology.

Such soil research is fundamental. It throws light upon the nitrogen changes that take place in soils and prepares the way for a study of the decreases in nitrogen in our agricultural lands, including those changes that take place as the result of human influence on the natural equilibrium established in a soil under its environment of climate, drainage, native vegetation, etc. The tide has turned from methods leading to decrease in soil fertility to an intelligent use of those methods that upbuild the Nation's resources in productive land.

LOW CROP production is due more often to lack of phosphorus than to the lack of any other element, but there is a wide difference in the deficiency of phosphorus in different soil types. Here the author discusses such questions as: What is the phosphorus content of various soils in the United States? How is the supply of phosphorus in the soil depleted? What are the available forms of phosphorus as distinguished from the unavailable forms? What crop plants respond most to additions of phosphorus? What is the influence of liming on phosphorus availability?

Phosphorus Deficiency and Soil Fertility

By W. H. Pierre[1]

PHOSPHORUS has sometimes been called the master key to agriculture. Its importance in general farming is indicated by the fact that low crop production is due more often to a lack of phosphorus than to the lack of any other element.

Phosphorus is found in every living cell and is essential in both plant and animal nutrition. In plants it is found in largest concentrations in the seeds, whereas in animals it makes up, along with calcium, the important elements found in the bones or skeleton. Adequate amounts of available phosphorus in soils favor rapid plant growth and development, hasten fruiting or maturity, and often improve the quality of the vegetation. In the Northern States where the growing season is short and early maturity is important, liberal supplies of phosphorus enable corn to mature before it is injured by the early freezes. On the other hand, low phosphorus content in the soil means not only delayed maturity and poor plant growth but a low phosphorus content of the plant. Thus, animals fed on plants grown in sections of this country and of other countries where the amounts of available phosphorus in the soils are very low, grow poorly and develop diseases that can be corrected only by supplying more phosphorus in their ration.

NEED OF PHOSPHORUS FOR MAINTAINING SOIL FERTILITY

Practical experience by farmers and the many experimental trials conducted on different soils by the various State agricultural experiment stations have shown that most soils respond to additions of phosphorus fertilizers. The only marked exceptions are the soils of

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the so-called bluegrass region of Kentucky and Tennessee, which were formed from rocks high in phosphorus and contain large amounts of total as well as available phosphorus. It is not the purpose of this

FIGURE 1.—Effects of manure and superphosphate, manure alone, and lime alone on yields of wheat and corn: *A*, The wheat on the left received lime alone and yielded 12.8 bushels per acre; that in the center received lime and manure and yielded 18 bushels per acre, and that on the right received lime, manure, and superphosphate and yielded 24.3 bushels per acre. (Wheat grown on Crosby silty clay loam, Randolph County, Ind.) *B*, The corn on the left received lime alone and yielded 18.6 bushels per acre; that in the center received lime and manure and yielded 58.7 bushels per acre, and that on the right, given lime, manure, and superphosphate, yielded 74.6 bushels per acre. (Corn grown on Bedford silt loam in Indiana.) (Photographs courtesy A. T. Wiancko, Indiana Agricultural Experiment Station.)

discussion to review the results obtained with phosphorus fertilizers in these hundreds of experiments, for they are available in detail in publications of the various experiment stations. Some of the experiments—as for example certain ones at the Illinois, Pennsylvania, Ohio, and New Jersey stations—have been continued on the same land for more than 50 years and have been especially valuable in determining the trend in yields from a particular phosphorus treatment over a period of years as well as in determining the residual effect of such treatment on the soil.

In addition to the long-time experiments there are in progress many experiments of shorter duration. These are planned to serve in determining not only the relative needs of phosphorus on different soils and for different crops but also, in many cases, the conditions that result in the most efficient and profitable use of the phosphorus already present in the soil as well as that added in fertilizers (fig. 1, *A* and *B*). Unfortunately, field experiments often have not been supplemented sufficiently by detailed studies in the laboratory and greenhouse so that the results obtained might be properly interpreted and applied to other conditions. In spite of this shortcoming, field experiments have been one of the safest guides to the maintenance of soil fertility and must be continued if the final answer to many soil fertility problems is to be found.

As might be expected, a wide difference is found in the deficiency of phosphorus in different soil types. In general, acid clay soils low in organic matter give greater responses to phosphorus fertilizers than other soils of the same region. In many cases, however, the extent of phosphorus deficiency is determined not by the soil type but by the treatment the soils have received since they were brought under cultivation. Phosphorus deficiency becomes evident after land is farmed for a few years, especially under a grain or livestock system of farming. It is not surprising, therefore, that the soils of the Eastern States showed the need of phosphorus first, and that most of the phosphorus as well as other fertilizers has been used in this general section. Experimental work done during the last 15 to 20 years, however, has definitely established the need of phosphorus fertilizer in the Great Plains region, and it is significant that in some cases a greater response to a given amount of phosphorus fertilizer is obtained in this region than in the Eastern States. Another evidence of the deficiency of phosphorus in American soils and in soils throughout the world is the large amount of phosphorus fertilizers used. In this country phosphate fertilizers make up approximately half of the tonnage of materials used in mixed fertilizers and half of the separate fertilizer materials bought by farmers as well.

The use of phosphorus-containing materials for improving soil productivity is not new. In fact the practice of using bones or fish for improving the productivity of soils is so old that there is no exact record of its origin. As early as 1653, an English writer mentioned the use of bones in British agriculture, but it was apparently not until about the time of the American Revolution that the practice of using ground bones on land became fairly general. Even at this later date the reason for the beneficial effect of bones was not understood.

By about 1815 the English supply of bones was low, and importa-

tions from other countries soon reached some 30,000 tons annually, showing that England was apparently more alert to the need for phosphorus than other European countries.

In the United States, the Indians had learned the value of applying fish in the hills of corn by the time of the first European settlement on these shores. As the fish decayed in the soil, phosphorus as well as nitrogen was liberated and made available to the plant. Although various bone fertilizers and guano were used in this country in the early part of the nineteenth century, it was not until after the Civil War that an American source of phosphorus became available and that much phosphorus was used on the land. In 1868 phosphorus fertilizers were first produced from the phosphate beds of South Carolina. Soon thereafter, the United States became the chief producer of superphosphate, and the farmers of this country have since had available a relatively cheap source of phosphorus fertilizer.

Although the total amount of phosphorus fertilizers used on American farms has been steadily increasing, the amount used per acre is still very small compared to that needed. There are three main reasons for the marked need for phosphorus by American soils: (1) A relatively low total supply, (2) removal of large amounts of phosphorus from soils by cropping and erosion, and (3) low availability of the phosphorus present and that added in fertilizers. Of these the last two are of greatest importance and are in need of increased consideration.

THE PHOSPHORUS CONTENT OF SOILS

Many determinations have been made of the total phosphorus content of different soil types. When these analyses were first made it was thought that they might help to determine which soils were in need of phosphorus and would respond best to phosphorus fertilizers. Field experiments with fertilizers soon showed, however, that the total phosphorus content of soils did not give a good measure of the amount of phosphorus available to the plant. Only a small portion of the total phosphorus content of soils becomes available to the plant, and the percentage that becomes available is different with different soils. Nevertheless, determinations of total phosphorus have been useful in getting a general picture of the reserves of phosphorus in the soil and the importance of conserving this supply. Van Hise (*439*),[2] in a book written nearly 30 years ago, stated: "The problem of the conservation of our phosphates is the most crucial, the most important, the most far-reaching with reference to the future of this Nation of any of the problems of conservation."

The phosphorus content of soils differs greatly. Thus many of the sandy soils of the Atlantic and Gulf Coastal Plains contain less than 500 pounds of phosphorus in the plowed layer (6⅔ inches) of an acre, usually considered to weight 2,000,000 pounds. Many of the most fertile soils of the country do not contain more than 1,200 to 1,500 pounds per acre (table 1). On an average, the percentage of phosphorus in surface soils is only about one-half that of nitrogen and one-twentieth that of potassium.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

One of the means of visualizing the phosphorus supplies of soils is to calculate the number of corn crops that could be grown if all the phosphorus of the surface soil were available to plants. It has been found that an average crop of corn of 60 bushels removes about 14 pounds of phosphorus per acre. This means that the soils that contain only 500 to 600 pounds of phosphorus per acre, plow depth, could support only about 40 sixty-bushel crops of corn, and that the soils that contain 1,400 pounds could support only 100 crops. These calculations do not take into account the phosphorus content of the subsoil, which may be utilized by deep-rooted plants in considerable amounts. On the other hand, only a small portion of the total phosphorus in the soil is available to plants. Therefore, low corn yields would result as soon as the available phosphorus supply became inadequate, and crop failure would occur long before all the phosphorus in the soil had been exhausted. Although the available supply of phosphorus must therefore be considered more important than the total supply, the above calculations based on total supply do emphasize the relatively small amount of reserve phosphorus in the soil.

Table 1.—*The phosphorus content of soils* [1]

Great soil group	Subgroup or soil series	Samples	States from which samples were taken	Phosphorus per acre: Range	Phosphorus per acre: Average
		Number		*Pounds*	*Pounds*
Podzol	7 different series	7	Massachusetts, Maine, Michigan, Minnesota, Pennsylvania.	80-960	620
Gray-Brown Podzolic.	Sassafras	4	Maryland, Virginia	18-1,320	410
	Collington	3	Maryland, New Jersey	780-1,040	880
	Nason, Manor, Leonardtown,	2	Virginia, District of Columbia	620-780	700
	Miami and associated soils.	10	Indiana, Ohio, Iowa, Kentucky.	520-4,020	1,320
	Clyde, Brookston, Clermont.	4	Indiana, Ohio	880-4,100	2,540
Red and Yellow	Norfolk, Tifton	15	North Carolina, South Carolina, Georgia, Florida, Alabama.	80-880	340
	Orangeburg, Greenville	5	Mississippi, Alabama, Georgia, Florida.	180-5,600	1,480
	Decatur, Hanceville, Nacogdoches.	3	Alabama, Texas	340-780	520
	Cecil, Georgeville	12	North Carolina, South Carolina, Georgia, Alabama.	80-1,840	620
	Durham, Appling, Porters.	5	North Carolina, Georgia	80-2,280	780
	Davidson, Iredell	3	North Carolina	340-1,840	1,040
Prairie	Northern Prairie	11	Nebraska, Iowa, Kansas, Missouri.	620-1,840	1,140
Chernozem	Northern Chernozems	6	South Dakota, Nebraska, Washington.	1,480-2,800	1,320
	Southern Chernozems	3	Texas	440-880	700
Dark Brown and Brown.	Northern Dark Brown	7	North Dakota, Nebraska, South Dakota, Wyoming.	960-2,100	1,320
Desert	Northern Gray Desert	5	Idaho, Nevada, Utah, Oregon	880-2,280	1,740
Pacific Coast	Mountainous areas	3	Idaho, Arizona	1,040-2,180	1,660

[1] Marbut, Soils of the United States (*240*).

DEPLETION OF SOIL PHOSPHORUS THROUGH CROP PRODUCTION AND SOIL EROSION

The phosphorus content of the soil is low not only because of low original amounts but also because cropping and soil erosion have

resulted in large losses. More than 30 years ago Whitson and Stoddart (*462*) found that soils in Wisconsin that had been cropped to grain for about 50 years had lost about one-third of the total phosphorus of the plowed layer. Similar results have been obtained in Ohio by Schollenberger (*346*). In a livestock or grain system of farming the products sold contain large amounts of phosphorus. The cereal grains contain about 75 percent of their total phosphorus in the seed. When the grain is sold off the farm, therefore, about 75 percent of the phosphorus that the plants obtained from the soil is lost. It should be emphasized also that the phosphorus removed by crops is the most available and therefore the most valuable portion present in soils.

Figure 2 Charles E. Thorne (1846–1936), director of the Ohio Agricultural Experiment Station 1887–1920, who started the classical long-time soil fertility work at the Ohio Station in 1893 and was one of the leading pioneers in soil fertility studies.

Under a livestock system it has been estimated that about 30 percent of the phosphorus in the feed is absorbed by the animal and another 20 percent is often lost in the manure. This means that only about one-half the phosphorus fed in the crops grown is returned to the soil in manure. Of interest in this connection are the following statements of Thorne (*402*) (fig. 2), one of the pioneers in the study of the maintenance of soil fertility:

Seven 1,000-bushel carloads of corn or oats, or five such carloads of wheat, carry away as much phosphorus as is found in the plowed surface of an average acre of land, even though the stover and straw are conscientiously returned to the land; and ten 13-ton carloads of mixed hay, or half that quantity of alfalfa hay, carry as much phosphorus as seven carloads of corn.

Some farmers assume that, if the hay and most of the grain are fed on the farm, there will be no loss of fertility; but the animal must find in its food the elements required to build its skeleton and other tissues. Six carloads of fat cattle, or 14 carloads of fat hogs, may contain phosphorus equivalent to that contained in the surface 6 inches of an acre, and the milk from a dairy of 130 average cows will carry off this quantity of phosphorus every year.

Thorne also makes the following significant statement:

The ultimate function of agriculture is to feed and clothe humanity, and the most important element in human food is phosphorus.[3] Under existing conditions

[3] It is questionable whether any necessary element in human food can be called the most important.

the greater part of the phosphorus consumed by mankind eventually finds its way to the sea or to the cemetery, so that there is a steady flow of this element from the soil which is never returned. Wherever, therefore, the land has been under cultivation for any considerable length of time there will be a deficiency of phosphorus, except in the rare instances in which the soil has been naturally stocked with an abnormal supply of this element.

In addition to the phosphorus removed from soils by cropping, large amounts are often lost from soils through erosion. Phosphorus is found chiefly in the finest particles of the soil, and it is these particles that are most easily carried away from the surface by running water or by wind. That large losses of phosphorus result from erosion is proved by the work of Miller and Krusekopf (*263*) of the Missouri Agricultural Experiment Station. Their results are shown graphically in figure 3. Where corn was grown continuously on land of 3.7 percent slope, more phosphorus was lost by erosion in 1 year than is found in a 75-bushel crop of corn. Even where a good rotation was practiced the loss of phosphorus by erosion was 6.2 pounds per acre, or as much as is found in an average 25-bushel crop of corn.

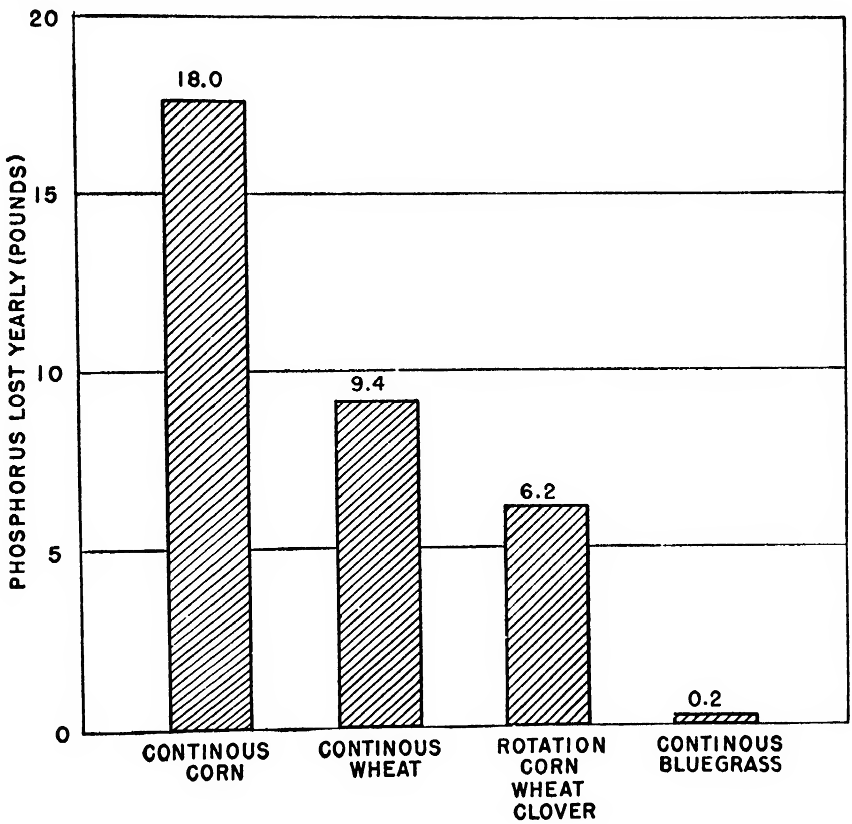

FIGURE 3.—Annual loss of phosphorus through soil erosion under different crops. (Courtesy Missouri Agricultural Experiment Station.)

Lipman and Conybeare (*220*), in a recent study of this problem, estimated that more than 2 million tons of phosphorus are lost annually in this country by erosion. This, as they have shown, is approximately equal to the estimated amount of phosphorus removed annually in harvested crops and by grazing (table 2). It is true, of course, that the phosphorus removed by erosion includes much that would become available to plants only very slowly; and that as the surface soil is eroded more phosphorus is brought to the surface from the subsoil. Although in some soils the total amount of phosphorus in the subsoil is not much lower than in the surface, the important consideration is that the phosphorus in the subsoil may be of much lower availability to plants.

The losses of phosphorus by cropping and by erosion explain in part the reason why most soils that are cropped for any length of time generally become deficient in available phosphorus. Obviously, it is not desirable to reduce the amount of phosphorus removed in crops. The problem of conserving soil phosphorus, therefore, lies primarily in reducing soil erosion, and in a careful saving and return to the soil of crop residues and manure.

Table 2.—*Balance sheet of phosphorus in the soils of the United States, 1930* [1]

Source of loss or gain	Phosphorus lost or added		Sources of loss or gain	Phosphorus lost or added	
	Tons	*Pounds per acre*		*Tons*	*Pounds per acre*
Losses:					
Harvested crops	696,527	3.8	Seeds	29,370	0.2
Grazing	1,344,019	.2	Roots and unharvested portion of crops	150,196	.9
Erosion (cropland only)	2,180,756	10.6			
Total [2]	4,221,302	9.6	Total [2]	1,417,835	3.3
Gains:			Net losses	2,773,467	6.3
Fertilizers	336,232	1.9			
Animal manure and bedding (harvested crop and pasture)	1,082,233	1.5			

[1] From preliminary data of Lipman and Conybeare (*220*).
[2] Based on total acreage in crops and pastures in farm.

THE AVAILABILITY OF SOIL PHOSPHORUS

It is less than a hundred years since Daubeny (1845) showed that only a part of the plant-food elements found in soils is available to the plant for growth and reproduction. Since that time numerous experiments have been conducted for the purpose of finding out how much of the total phosphorus in the soil is available to plants and how the remainder can be made available. That the percentage of the total phosphate available to plants during a crop season is small is shown by the fact that crop yields are often increased from 50 to 100 percent by the addition of a few pounds per acre of phosphorus in fertilizer although the soil may contain 1,000 pounds or more per acre. Can this storehouse be tapped? And how do soils differ in the amounts of phosphorus that are available or can be made available to plants?

It is generally accepted that before phosphorus and other nutrients can be taken up by the plant roots they have to be dissolved in the water of the soil, or the soil solution. At any one time the amount of phosphorus in the soil solution is very small. Thus, even in the most fertile soils the concentration is usually less than one-half part of phosphorus in 1,000,000 parts of water (*303*). Since there is only about 500,000 pounds of water per acre in the surface soil when it contains 25 percent of water, it follows that there is at most not more than one-fourth of a pound of phosphorus present. This amount of phosphorus is only about 2 percent of the amount required to grow a 50-bushel crop of corn. Fortunately, this is not the only phosphorus available to plants during the growing season. As the plant roots absorb the phosphorus from the soil solution, more phosphorus comes into solution from the solid particles of the soil. Therefore, it is the the rate at which the phosphorus compounds of the soil can dissolve in the soil solution that is important. If more phosphorus is rapidly brought into solution as the plant roots absorb that which was present, there is no deficiency of phosphorus even though the concentration in the solution may never be over one-half part in a million parts of water. On the other hand, if the phosphorus does not come into solution rapidly the plants are likely to suffer from a lack of available phosphorus. The rate at which the phosphorus in the soil solution can be renewed is dependent to a large extent on the combinations or compounds in which the phosphorus exists in the soil. Before discussing the various phosphorus compounds of the soil, however, it seems desirable to consider briefly the part played by plants in obtaining phosphorus from soils.

DIFFERENCES IN ABILITY OF PLANTS TO OBTAIN PHOSPHORUS FROM SOILS

It is a well-recognized fact that certain plants are able to grow on soils that are very infertile and low in available phosphorus. This is particularly true of many weeds and native plants of relatively low economic value. In the Northeastern States, for example, many permanent pastures contain such poor native grasses as *Danthonia spicata*, commonly known as poverty grass or moonshine grass, and *Andropogon virginicus*, or broomsedge. These plants often make a fairly dense sod on soils very low in readily available phosphorus. They thus help in preventing erosion, and they also furnish considerable pasture, although the quality of the herbage and the total growth are much lower than those of the better types of pasture plants such as bluegrass and white clover. When pastures supporting mostly poverty grass and broomsedge are top dressed with phosphorus[4] it has been shown that Kentucky bluegrass and white clover tend to crowd out the poorer plants (*285*). This is an interesting example of plant competition. Although the plants of the poorer type are also benefited, the increased amount of available phosphorus in the soil makes it possible for the better species to crowd out those that were able to grow with less available phosphorus.

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[4] Lime is also necessary on most of these pastures, but lime will not usually bring back the bluegrass and clover unless phosphorus is also added.

Among the various harvested crop plants also there are wide differences in ability to grow on soils low in phosphorus. Rye and oats have generally been considered to be able to grow well on soils where barley would suffer from a lack of available phosphorus. Recently, Chapman (*64*) found that citrus seedlings gave no response to phosphorus fertilizer on certain California soils that fail to grow alfalfa unless phosphorus fertilizers are applied. Possibly the most comprehensive work on this question that has been reported is that by Hartwell and Damon (*152*) at the Rhode Island Agricultural Experiment Station. These investigators conclude from their studies: Relatively, beets, cabbages, rape, rutabagas were high-phosphorus-response crops, that is, they were not successful in supplying their needs from the soil itself. In opposition to the preceding, carrots, millet, potatoes, tomatoes, and spring wheat were low-response crops; leaving soybeans, corn, and oats as intermediate. It should be recognized that these data are based on work with only one soil, and that even the low-response crops listed here gave responses to phosphorus fertilizers and have been shown in many other experiments to give good response on soils low in available phosphorus.

Much more work needs to be done before crops can be definitely classified in regard to their ability to grow on soils of different phosphorus levels, and before the differences existing can be adequately explained. It is evident that such information has practical application in establishing sound fertilizer practices and in utilizing most efficiently the phosphorus present in soils. Even though some of the plants that are able to obtain phosphorus readily from soils are of low crop value, they may be very valuable as green-manuring crops, for when they are incorporated in the soil the phosphorus they contain may become readily available to the following crops.

Not only do different species of plants differ in their ability to absorb and utilize the phosphorus and other nutrient elements of the soil, but some recent work shows that different varieties or strains of the same species vary in their ability to utilize soil nutrients. This was first demonstrated in 1928 by English investigators who were working with varieties of barley (*133*). Since then, various investigators in this country have shown that there are varietal differences in the utilization of soil phosphorus and in the response to phosphorus fertilization (*269, 390*). Such studies show the importance of a greater consideration of soils in variety trials and point to the possibility of breeding plants of greater efficiency in the utilization of phosphorus and other elements native to the soil or applied as fertilizers.

Many studies have been conducted in an attempt to learn why certain crops can obtain more phosphorus from soils than others and can make more growth on soils low in phosphorus. One of the most plausible explanations of the difference in the feeding power [5] of plants for phosphorus is the difference in the size and character of the root system, plants with a large root system being better able to obtain phosphorus from a soil solution of low concentration. Sommer (*373*) recently found that in solution cultures wheat and buckwheat, which have a large root system or large absorbing surface, made a better

[5] By feeding power is meant the ability of the plants to absorb soil nutrients and to utilize these in growth.

growth at low concentrations of phosphorus than cotton, which develops a relatively poor root system.

The rate at which a plant grows may also affect its ability to obtain sufficient phosphorus from the soil solution. If it requires a large amount of soluble phosphorus during a very short time, the phosphorus compounds in the soil may not be able to replenish the soil solution fast enough to furnish the crop needs. Other theories that have been proposed for explaining the difference in the ability of plants to obtain phosphorus from the soil will not be discussed here since good reviews are available in the literature (*399, 413, 415*). It is evident that a complete explanation of this problem must await further studies.

Phosphorus Compounds in Soils

Of even greater importance than the plant itself in determining the amount of phosphorus absorbed in plant growth is the kind of phosphorus compounds present, since, as previously indicated, these compounds largely determine the rate at which the soil solution can be replenished with phosphorus. A knowledge of these compounds and their availability is therefore important to a better understanding of the soil-phosphorus problem. Unfortunately it has not been possible to isolate these compounds of phosphorus from the soil, and progress on this problem has been relatively slow. It has been established, however, that there exist in soils different compounds of phosphorus that have different degrees of solubility (*112, 157, 229, 346, 347*). The four main groups of phosphorus compounds in soils [6] are:

(1) Compounds of calcium and phosphorus or magnesium and phosphorus.
(2) Combination of phosphorus with organic matter.
(3) Compounds of iron and aluminum and phosphorus.
(4) Compounds of phosphorus present in rock from which soils are formed (apatite class).

The groups are listed in what is believed to be the order of decreasing availability. The most available compounds are those containing calcium and phosphorus either in the form of monocalcium phosphate or dicalcium phosphate.[7] It is these compounds that are present in superphosphate fertilizers.

The organic phosphate compounds are present in the organic matter of soils and therefore are found mostly in the surface soil. Schollenberger (*346*) has shown that in the surface of average Ohio soils approximately one-third of the phosphorus is in organic combinations, while in the subsoil about one-fifth of the total phosphorus is in this form. The real value and availability of these organic phosphorus compounds is not well known. That much of the organic phosphorus of soils is not very readily available is evidenced by the fact that soils high in organic phosphorus are often as badly in need of phosphorus fertilizers as those lower in these compounds. In general, however, it is believed that the presence of organic matter in soils has a beneficial effect on the availability of phosphorus. This is

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[6] In addition to these four groups there is recent evidence that phosphorus exists in the colloid or clay complex of soils in a form in which it is exchangeable with other anions (*307*). This group may be found to be of considerable importance.

[7] In alkaline or calcareous soils there are also present more basic forms of calcium phosphate, which under the existing conditions have a relatively low availability to plants (*229*).

indicated by some recent work of Hester and Sheldon (*162a*) with Norfolk fine sandy loam at the Virginia Truck Station. In their studies the organic matter of the soil was raised by the addition of peat moss and the phosphorus content by additions of various amounts of superphosphate. They found that lima beans gave marked increases in yields from additions of superphosphate, but that where the organic matter of the soil had been raised to 3 percent good yields were obtained with only one-third as much phosphorus as where the organic matter content was only 1 percent. These workers believe that the presence of organic matter delayed the absorption of phosphorus by iron and aluminum and thus kept it more available to the plants. In fresh organic matter incorporated in soils, such as green manures, the phosphorus in organic compounds may constitute one-half or more of the total amount present. Some of these organic phosphates are readily decomposed by soil bacteria and made available to plants.

The third group of phosphorus compounds listed, the iron and aluminum phosphates, are generally considered to be of low availability to plants. There is probably a considerable number of these compounds in the soil, some of which are more available to plants than others. Thus Truog (*413*) found that iron and aluminum phosphates that are freshly prepared in the laboratory are available to certain plants. Although some of the iron phosphate compounds in the soil may be of a similar nature, it is generally believed that most of them liberate phosphate into solution so slowly that they are of relatively low availability to most agricultural plants. Soils that contain phosphorus mostly as iron and aluminum phosphates can therefore be expected to be in need of phosphorus fertilizers for optimum growth of most crops.

The fourth group comprises those phosphate compounds that are present in the mineral form in the rock from which the soil was derived. These are believed to be very resistant to the action of water and other solvents present in the soil and therefore of low availability to plants.

Although, as will be seen later in this discussion, the present knowledge of the compounds in which phosphorus is present in soils has helped toward a better understanding of the problem of phosphorus deficiency in different soils, much yet needs to be known. It is entirely probable that other compounds than those listed are very important. A better knowledge of the kind of compounds present in different soil types and under different conditions should help in utilizing more efficiently the native soil phosphorus as well as that added in fertilizers.

Influence of Liming on the Availability of Phosphorus

For many years it has been believed that the phosphorus compounds of acid soils are less available than those in well-limed soils. More than 30 years ago Whitson and Stoddart (*461*) studied the response of soils to phosphate fertilization and found that the acid soils with which they worked gave a much greater response to phosphorus fertilizer than the nonacid soils. They suggested that in the acid soils the phosphorus was largely present as iron and aluminum phosphates

instead of the more available calcium phosphates. This conclusion was supported by their laboratory studies, which indicated that the ratio of iron and aluminum phosphates to calcium phosphates was higher in the acid soils. Much work on this problem has been done since that time; and although there has been some apparent contradiction in the results (*14*), it may be concluded from the available evidence that on many acid soils moderate liming, practiced over a period of years, has resulted in making the phosphate compounds in the soil more available. This is what might be expected, since liming increases the calcium content of soils. The phosphorus that is present as iron and aluminum phosphate can thus be converted in part to the more available calcium phosphates. It is also probable that liming results in a liberation of the organic phosphorus compounds in the soil through stimulation of decomposition processes.

Parker and Tidmore (*293*) studied the soils from differently treated plots of long-continued field experiments in Alabama, Illinois, Ohio, and Kentucky and found that the soil solutions from the plots that received lime were much higher in phosphorus than from plots that had not received lime. Other investigators have studied the effect of lime on phosphate availability by the use of various acid solutions. Since, however, the exact value of these solutions in indicating the amount of phosphorus available to plants has not been fully established, the results obtained in such studies need not be reviewed here.

Crop-yield data available also support the conclusion that the liming of acid soils over a period of time renders the phosphorus of the soil more available to plants. Probably the most valuable and comprehensive data of this kind are those by Salter and Barnes (*334*) of the Ohio station. These investigators studied the response of 11 different crops to applications of superphosphate fertilizer on a Canfield silt loam that had been brought to different pH values[8] by liming. On the soil that was medium to very slightly acid, superphosphate gave good increases in yield, but where lime was used in amounts slightly greater than to neutralize all soil acidity the yields were just as high where no superphosphate had been applied. It was concluded that the lack of response to superphosphate was largely due to the fact that the lime had increased the availability of the native soil phosphate to such an extent that the plants needed no additional amounts. Other experiments by these workers on very similar soils supported this conclusion. It is evident, therefore, that liming is a very practical means of increasing the availability of phosphorus to plants on these soils. Because of the practical importance of the problem, more work of this kind is needed on soils of widely different character, especially since the results will no doubt differ with different soils.

It must be emphasized that lime alone will not solve the problem of phosphorus availability. Many soils have been so depleted of phosphorus that lime has little effect in increasing crop yields unless accompanied by applications of fertilizer containing considerable amounts of phosphorus. The old adage, "Lime and lime without manure will make both farm and farmer poor," emphasizes the fact that lime will only temporarily maintain a sufficient supply of available plant food for good crop growth.

[8] See Glossary, p. 1173.

It should also be recognized that on certain very acid soils the application of large amounts of lime may temporarily result in symptoms of phosphorus starvation and poor plant growth (*302, 340*). It should be emphasized, however, that this is a temporary effect and that when the equilibrium in the soil has been thoroughly reestablished, which takes place rapidly under field conditions, the effect of the lime on acid soils is to increase the availability of the soil phosphorus or that applied as fertilizer.

AVAILABILITY AND UTILIZATION OF PHOSPHORUS ADDED IN FERTILIZERS

As previously stated, the efficient production of many crops in the older sections of the country is dependent on the use of fertilizers high in phosphorus. For most crops it is found that in order to obtain optimum yields a much larger amount of phosphorus must be applied than is eventually removed in the first year's crop. The reason for this is that when a phosphorus fertilizer is applied to the soil it soon combines with the soil to form the compounds discussed in the previous section. Since some of these compounds are but slightly available to plants, only a part of the phosphorus added in fertilizers is available for the immediate crop. The process by which phosphorus fertilizers combine with the soil is commonly known as fixation. It is a process of great practical importance, for it determines the efficiency of phosphorus fertilizers on different soil types. If the phosphorus is largely absorbed, or fixed, by the soil through the formation of certain compounds of iron and aluminum, the phosphorus has a low availability to plants and therefore a low efficiency.

Much work has been done on the problem of phosphorus fixation in soils. It has been found that soils of different types vary greatly in their tendency to convert some of the phosphorus added in fertilizers into forms relatively unavailable to plants. The organic matter content and the lime status of soils, which have previously been shown to influence the availability of the native soil phosphorus, likewise influence the availability of that added in fertilizers. In addition, it has recently been found that the chemical nature of the clay and of the very fine particles of the soil, the soil colloids, markedly affect the amount of phosphorus fixed in unavailable form (*123, 157, 339*).

In a very interesting and valuable experiment, Gile (*123*) determined the effect of isolated colloidal fractions of different soils on the utilization of superphosphate by millet in sand cultures. The colloids from four of the soils studied increased the efficiency of the superphosphate, whereas the yields of the millet in the cultures to which the colloids of the other 13 soils had been added were only 1 to 71 percent as high as where no colloids were present. This indicates that the clay and colloids from some soils had a much greater effect in rendering the superphosphate unavailable to plants than those from other soils. Those colloids that had a high amount of iron and aluminum as compared with silica had the greatest effect in reducing the availability of the phosphorus. These results are in agreement with those of Scarseth and Tidmore (*339*). It is apparent, therefore, that where large amounts of active iron and aluminum are present in the soil they tend to fix the phosphorus in relatively unavailable forms. In general,

the red and yellow soils of the Southeastern States have a higher ratio of iron and aluminum to silica in their colloids than most of the gray and brown soils of the northern and western parts of the United States.

Not only does the character of the soil affect the percentage of the phosphorus that is fixed in less available form, but the amount of phosphorus applied and the time elapsed since the application are also important. The longer the phosphate remains in the soil the larger will be the percentage fixed in less available form. On the other hand, the more the compounds of the soil become saturated with phosphorus, the smaller will be the percentage of the phosphorus fertilizer that is held in unavailable form. This may be compared to the holding of water by a sponge. When only a small amount of water is added to a dry sponge, it is held very tightly, but as more water is absorbed the less tightly it is held and the more easily it is squeezed out.

Since the phosphorus added in fertilizers is held largely by the clay and colloidal particles, it follows that, other factors being equal, clay loam soils will fix a larger amount of phosphorus in unavailable form than sandy soils lower in clay and colloids.

Residual Effect of Phosphorus Fertilizers

The question as to what percentage of the phosphorus added in fertilizers is recovered by the first year's crop and what percentage is available for succeeding crops is one of considerable practical importance. The objective in the use of fertilizers is, of course, to recover in increased crop growth as much of the added plant nutrient as possible. This amount will vary with the type of soil and kind of plant, as described, and also with the amount and kind of fertilizer applied. In general, experimental work shows that in broadcast applications under ordinary conditions not more than 10 to 20 percent of the phosphorus applied is recovered in the first crop (*182*, *334*). In meadow and pasture crops where the fertilizer is applied on the surface this value is even less. Some of the residual phosphorus is recovered in succeeding years, but little data are available as to the percentages recovered. In a pasture experiment now in progress at the West Virginia Agricultural Experiment Station the application of 500 pounds of superphosphate per acre in 1930 and again in 1932 still exerted a marked effect 4½ years after the last application, not only on the yield and the type of vegetation but also on the phosphorus content of the herbage. Although the herbage had been removed ever since the first application of superphosphate was made 6½ years previously, the percentage of the added phosphorus that was recovered in the herbage during that period ranged from only about 20 to 30 percent.

From an immediate practical viewpoint the question may not be so much the percentage of the phosphorus recovered in succeeding years as the residual effect, shown by increased yields. Although there are little recorded data on the length of time an application of phosphorus to one crop in the rotation will increase the yield of succeeding crops, it is a common observation in ordinary farm practice that a response is often obtained from an application of phosphorus made to the preceding crop. With perennial crops such as alfalfa and pasture grasses, response data for a number of years following the treatment are avail-

able. Yield data were obtained for 4 years after applying the fertilizer and seeding the alfalfa. It will be noted that the increase in yield from the use of 500 pounds of 20-percent superphosphate per acre was still 37 percent during the fourth year as compared with an increase of 54 percent during the first year. Samples of soil removed 3 years after fertilization still showed nearly twice as much available phosphorus as those from the untreated soil, whereas the soil that had received the 1,000-pound application of superphosphate had more than three times as much available phosphorus in the 0 to 3 inch layer.

The problem of the residual effect of fertilizers is an important one under a tenant system of farming. How is the tenant to obtain full credit for the fertilizer he applies to the soil? The British farmer has for many years recognized this problem and has adopted a method of compensating the tenant for fertilizer unused at the expiration of his tenancy. This method is summarized in a recent article by Smalley (*362*):

> When a tenant leaves a farm, he is given credit for all improvements that he has made, including improvement in soil fertility. For many years tables have been in use showing the composition, manurial, and compensation values of various feeding stuffs, and the compensation which should be allowed for fertilizers applied. These tables have recently been revised by a committee representing various agricultural institutions and farmers' organizations. For example, it is estimated that 40 percent of the nitrogen, 75 percent of the phosphoric acid, and 75 percent of the potash contained in a feeding stuff will be found in the manure and that half the value of the manure will remain after one crop has been grown. Another table shows the value of various fertilizers remaining in the soil after the first, second, and third crops are removed. In the case of superphosphate, for example, it is estimated that two-thirds of the value remains after the first crop, one-third after the second crop, and one-sixth after the third crop; whereas in the case of mixed fertilizer it is estimated that one-third of the value remains after the first crop, one-sixth after the second crop, and none after the third crop.

Such a system tends to encourage the tenant farmer to maintain the productivity of the soil and might very well be considered under certain types of tenancy in this country.

Accumulation of Phosphorus in Soil Through Fertilization

Since only a portion of the phosphorus added in fertilizers is recovered in the crops and since there is very little if any leaching of phosphorus fertilizers, the question arises as to whether their continued use will not eventually raise the total phosphorus content of soils until sufficient available phosphorus is present to meet the crop needs. The answer to this problem depends on two factors, the amount of fertilizer used and the loss from the soil through crop removal and through erosion. From the earlier discussion on erosion losses, it is obvious that no accumulation will take place on many soils where the rate of application of phosphorus is low. In general farming, for example, the annual application of 20-percent superphosphate is seldom more than 200 pounds per acre per year, and usually much less. Two hundred pounds of 20-percent superphosphate contains approximately 18 pounds of phosphorus. Since crops remove an average of 10 to 20 pounds of phosphorus a year, it is obvious that not much accumulation of phosphorus will take place unless the crop residues and the manure are carefully saved and returned to the land, and unless soil

erosion is largely prevented. It is possible, however, through the use of good farm practices, to have a gradual accumulation of phosphorus in the soil from the addition of a yearly application of 200 pounds of superphosphate. In cotton farming, for example, only a small portion of the phosphorus is removed from the soil in the seed cotton, and a slow accumulation may be expected if erosion is carefully controlled.

Under more intensive types of agriculture, where large amounts of fertilizer are used, the accumulation of phosphorus over a period of years may be considerable. This has been well demonstrated by work at the Connecticut, Florida, and Virginia Truck Stations (*17*, *54*, *161*). Anderson et al. (*17*) obtained no response to phosphorus fertilizer on the old tobacco soils of Connecticut, and attributed these results to the long-continued, heavy applications of phosphorus which have built up a large surplus of total and available phosphorus. This is shown by their analyses of 68 soils taken from the tobacco-growing section of Connecticut. The soils that had been in tobacco for less than 5 years averaged 1,528 pounds of total phosphorus per acre, those that had been cropped to tobacco 5 to 20 years averaged 2,655 pounds, and those in tobacco for 20 or more years averaged 3,855 pounds. These large accumulations of phosphorus are not surprising when it is considered that heavy applications of fertilizer, containing at least 60 pounds of phosphorus (equivalent to approximately 700 pounds of 20-percent superphosphate), have usually been applied each year. The authors conclude:

> On old tobacco fields it is reasonable to believe that the grower may greatly reduce or eliminate phosphorus carriers from his fertilizer mixture for many years to come . . . A very large part of New England's thirty-five thousand acres of tobacco is grown on old tobacco land. The annual bill for phosphorus on these acres is approximately a quarter of a million dollars. At least half of it is unnecessary.

Similar accumulations of phosphorus have been found by Hester (*161*) in the soils of eastern Virginia that have been producing vegetable crops since about 1850 and have received large amounts of fertilizers; and also by Bryan (*54*), in the citrus soils of Florida, where some of the old seedling groves were found to have an average phosphorus accumulation equivalent to more than 60,000 pounds of superphosphate (16-percent) per acre-foot.

These conditions, it should be remembered, are representative only of very intensive types of agriculture. The results obtained, however, are valuable in demonstrating what may also occur to a less extent under less intensive fertilization.

Practical Means of Increasing the Availability of Applied Phosphorus

The better understanding of the problem of phosphorus fixation in recent years is resulting in practices and developments that will mean a more efficient use of phosphorus fertilizers. The most important of these is the practice of hill or row fertilization whereby the fertilizer is distributed in narrow bands on the side of the seed instead of being broadcast and mixed with the whole mass of soil. The results of many experiments conducted in different parts of the country show that when the fertilizer is properly placed with respect to the

seed, the yields obtained are much better from row or hill applications than from the use of a similar amount of fertilizer applied broadcast (*147*).[9] *One of the main reasons for these results is that the phosphorus applied in the fertilizer is kept in a more available condition.* When the fertilizer is applied broadcast the phosphorus particles come in contact with a large amount of soil and the phosphorus is therefore rapidly fixed in a condition not readily available to plants.

The use of granular or pellet forms of fertilizers instead of the ordinary finely powdered forms should also result in less fixation of the phosphorus in unavailable forms and therefore in increased efficiency of the fertilizer. A large number of experiments are now in progress with granular fertilizers in different sections of the country and the results obtained will be watched with considerable interest. If the value of the granular product is clearly demonstrated, there seems to be little doubt that it will largely replace the finely powdered form.

While the methods of fertilizer application to row crops and to other crops in the rotation have led to an increased efficiency of the phosphorus fertilizer, little has been accomplished in the way of increasing the efficiency of phosphorus applied as top dressings to permanent pastures and meadows. Since phosphorus fertilizers become readily fixed by the soil, the downward movement into the soil root zone of phosphorus fertilizers applied as top dressings is very slow. As an example of this slow downward movement can be cited some unpublished data obtained at the West Virginia Agricultural Experiment Station. Phosphorus fertilizer was applied at the rate of 500 pounds of 20-percent superphosphate to a permanent pasture on Dekalb silt loam in 1930, when the experiment was started, and again in 1932. In the fall of 1937 soil samples were removed from the 0 to 1½ inch, the 1½ to 3 inch, and the 3 to 5 inch depth and analyzed for available phosphorus. The results showed that the phosphorus had penetrated only slightly below the 1½-inch layer and none had penetrated below 3 inches.

The slow downward movement of phosphorus in permanent pastures means that it often takes about 2 years before much improvement in the vegetation is obtained. This is well illustrated in figure 4. Since large areas of permanent pastures in the Eastern States are either too rolling to be plowed without serious losses from erosion or too stony for use of farm implements, the problem of incorporating the fertilizer in the soil so as to get more efficient use of the phosphorus is difficult. A similar problem arises in the fertilization of orchards, and it is believed by some investigators that the failure to get response from phosphorus in orchards is partly due to the fact that the phosphorus is fixed in the soil before it reaches the zone of greatest root concentration.

One of the possibilities of increasing the downward movement of surface-applied phosphorus that has been suggested is to produce a phosphorus fertilizer that is not readily fixed by the soil but will dissolve in the soil solution and move downward more readily. Midgley (*256*) found that pure disodium phosphate moved downward into the soil more quickly than did superphosphate. These results

[9] See article on Methods of Applying Fertilizers, p. 546.

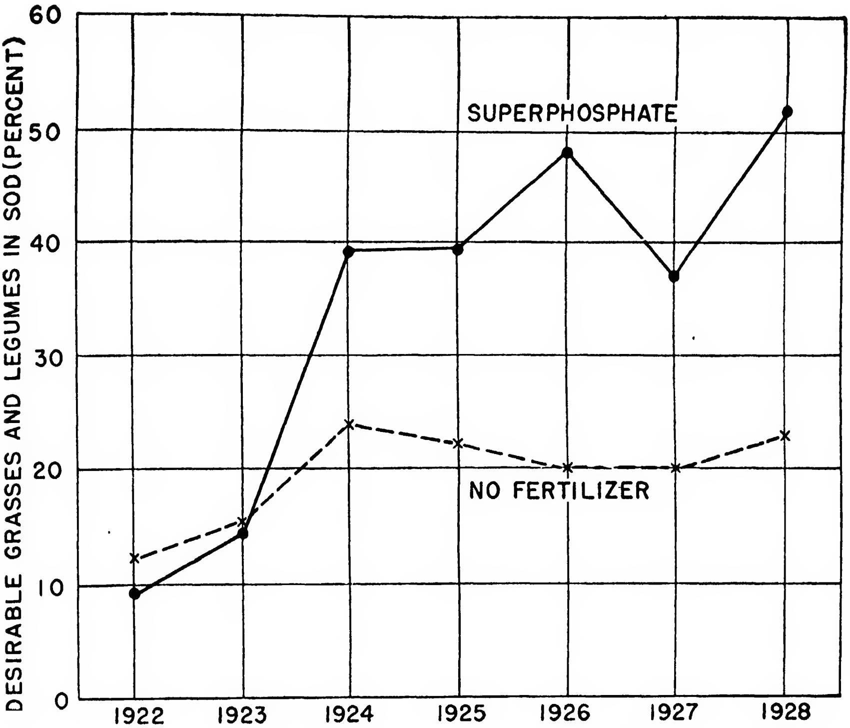

FIGURE 4. The rate at which top dressings of superphosphate increase the percentage of desirable grasses and clovers in a permanent pasture. The superphosphate (16-percent) was applied at the rate of 300 pounds per acre in the fall of 1922 and again in the spring of 1926.

PHOSPHORUS NEEDS AND SOIL CONSERVATION

have been confirmed by Spencer and Stewart (*376*). The latter investigators also studied the use of some organic phosphorus compounds prepared in the laboratory and found that under irrigation they moved downward into the soil at a rate much faster than inorganic phosphorus compounds.

It is evident from this brief discussion, therefore, that there is need for further studies of the best means of applying fertilizers to perennial crops to insure the greatest efficiency of the phosphorus.

The attention given to the problem of soil conservation during the past few years has emphasized more than ever the importance of phosphorus in any system of permanent soil fertility. It has been indicated that the greatest loss of phosphorus from may soils comes through erosion (table 2). Conversely, it can be stated that one of the important causes of erosion is a low content of available phosphorus. This close relationship between soil conservation and the phosphorus content of soils is readily evident if it is recognized that one of the best means of controlling erosion is to maintain a good plant cover, and that this cannot be done effectively on phosphorus-deficient

soils. Phosphorus fertilization on both crop and pasture land is particularly essential in the growing of legumes, crops which not only furnish an excellent vegetative cover, but are able to grow on nitrogen-deficient soils and restore to these soils the much-needed nitrogen and organic matter so essential to economical crop production.

A thorough consideration of the phosphorus problem clearly shows that the amount of phosphorus used on American farms (*251*) is only a fraction of that which is needed. Thus far, practically all the phosphorus fertilizer has been used on cropland. The greater recognition of the importance of pastures in a permanent system of economic crop production and wise land use will no doubt lead to a greater use of phosphorus on pasture land. For many years there has been a continual removal of phosphorus from such soils, until today many pastures support only the poorer species of plants, which produce scant herbage of relatively low quality. What percentage of these pastures can be economically improved still remains a question. If, however, one-fourth of the pasture land of the eastern United States were to receive 100 pounds per acre of superphosphate annually, there would be needed, according to Salter (*333*), a total of 1,250,000 tons annually. This amount is equal to about one-half of the total phosphorus now used in the entire country for all crops.

A greater need of phosphorus by harvested cropland is also well recognized. Much time, effort, and money is now being spent in an attempt to produce crops on land too low in available phosphorus to make production economical. From the standpoint of the future welfare of the country such production is actually detrimental, for it means large losses of topsoil by erosion. It is evident, therefore, that phosphorus must play an increasingly important role in the development of a national soil conservation program and in a permanent system of agriculture.

WHAT *is the importance of potassium to plants? What plants need it most? What are the effects of "potash hunger" on cotton, tobacco, potatoes, and other crops? How is the soil depleted of potash? Why does potash act differently in different soils? These and other questions are discussed in this article.*

Soil Potassium in Relation to Soil Fertility

By H. P. Cooper, Oswald Schreiner, *and* B. E. Brown [1]

POTASSIUM is very widely distributed in the earth's crust as a constituent of silicate minerals such as orthoclase and microcline, and certain forms of mica, chiefly muscovite. Under the influence of various weathering factors, principally temperature changes and the action of water, these and other potash-containing silicates are converted slowly to ordinary clay, termed kaolinite, and water-soluble potassium.

Oceanic waters contain only about 0.04 percent of potassium in contrast with about 2.45 percent in the earth's crust. Even with such wide distribution of potassium in the earth's crust and in the ocean, accumulation of soluble potassium compounds suitable for fertilizer purposes occur in large quantities in but few places, chiefly in Germany and France. In recent years underground deposits of commercial importance have been found in the United States, principally in the Southwest. In the European deposits the crude potassium salts occur as layers 80 to 100 feet thick, covering strata of common salt, which indicates that their origin was oceanic. The principal source in these highly developed potash mines are carnallite, consisting of potassium and magnesium chloride; and kainite, composed of magnesium sulphate and potassium chloride. Sylvite, chiefly potassium chloride, occurs principally in the Alsatian mines. Another source, although a comparatively minor one, is potassium nitrate found associated with sodium nitrate in Chile and Peru.

Inasmuch as soils are produced by the breaking down of rocks by the process of weathering, all soils contain potassium in the potash-bearing constituents, such as feldspar, occurring in these rocks. Investigators time and again have shown that practically all the potash

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minerals originally present in rocks are found as such in arable soils. As the potassium in such minerals becomes available or as potassium salt is added to the soil in the form of fertilizer, crop plants utilize its compounds as is evidenced by an analysis of their ash, in which the potassium is found principally as potassium carbonate, although occurring in the living plant in both organic and inorganic combinations. Since human beings and animals of all kinds obtain their food supply directly or indirectly from plants, it is not surprising that potassium is found in all animal tissues and secretions, such as muscles, blood, urine, albumen, eggs, milk, hair, etc. The dependence of all life upon potassium is, therefore, as self-evident as is the case with nitrogen or phosphorus.

QUANTITY OF POTASSIUM IN SOILS

Unlike nitrogen and phosphorus the quantity of potassium found in soils is comparatively high. A mineral soil with a nitrogen content of 0.2 percent—about 4,000 pounds of nitrogen in 6 or 7 inches of topsoil—is considered to be well supplied with this particular element, and the same applies to phosphorus. A soil with only 0.2 percent of total potassium would be rated very low in this element. There are some cultivable soils, such as sands and light sandy loams with pervious subsoils, and mucks and peats, which are generally not only very deficient in available potassium but quite low in total potassium. It is such soils that give the most striking response to applications of available potassium in fertilizers. The ordinary range of potassium, expressed as the oxide (K_2O), in the upper or plow surface of mineral soils will range from 0.15 percent in sands to 4 percent and over in clay soils. Taken as a whole, however, the general run of soils contain fairly large quantities of potash, averaging approximately 2 percent. This means about 40,000 pounds of potash in the plow layer whereas nitrogen will hardly exceed 4,000 pounds and phosphoric acid 3,000 pounds. It is important to consider, however, that even with such a large reserve of potash in soils it is generally present in relatively insoluble compounds. A chemical analysis of a few typical soils, ranging in texture from sand to clay, shown in table 1, will help to bring out the variation in potash in different soils and the relation of this constituent to depth of soil.

Table 1.—*Potash (K_2O) content in different soils at varying depths* [1]

Soil type	Location	Depth	Potash (K_2O) content	Soil type	Location	Depth	Potash (K_2O) content
		Inches	*Percent*			*Inches*	*Percent*
Lakewood sand	New Jersey	0-8	0.163	Canfield silt loam	New York	0-8	2.02
		8-24	.245			8-24	2.35
Sassafras sand	do.	0-8	.233			24-36	2.71
		8-24	.287	Vergennes clay loam	do	0-8	2.57
Sassafras fine sandy loam	do	0-8	.737			8-24	2.94
		8-24	.833			24-36	3.23
Dunellen sandy loam	do	0-8	1.009	Vergennes clay	do	0-8	3.51
		8-24	1.25			8-24	3.91
Merrimac loam	do	0-8	1.46			24-36	3.96
		8-24	1.54				

[1] New Jersey analyses reported in (*37a*); New York soils in (*34a*).[2]
[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

POTASSIUM REMOVED BY CROPS

In practically every type of farming a fairly heavy drain on the supply of available potash takes place annually. This is well shown by plant analysis, which discloses that potassium is freely removed from the soil. It is essential therefore that the supply of available potassium be maintained at a proper level. This is particularly true of tuber crops and those producing starch or sugar. Some idea of how much potassium is utilized by different crop plants is shown in table 2 taken from Van Slyke (*441*).

Table 2.—*Approximate amount of potash* (K_2O) *in different crops*

Crop	Portion of crop	Yield per acre	K_2O removed
			Pounds
Corn	Grain	25 bushels	5.5
	Stalks	1,500 pounds	21.0
	Cobs	250 pounds	1.1
Total			27.6
Wheat	Grain	25 bushels	6.0
	Straw	2,500 pounds	15.0
Total			21.0
Rye	Grain	20 bushels	6.7
	Straw	2,000 pounds	17.0
Total			23.7
Oats	Grain	25 bushels	4.8
	Straw	1,250 pounds	15.6
Total			20.4
Alfalfa [1]		10 tons	100
Clover, red [1]		6 tons	60
Potatoes		150 bushels	45
Sweet potatoes		200 bushels	55
Beets, common		12½ tons	125
Turnips, common		10 tons	90
Carrots		5 tons	53
Cotton	(Total crop)		32.2
Tobacco	Leaves	1,000 pounds	57.5
	Stalks		20.5
Total			78.0
Sugarcane	Stalks stripped	15 tons	18.3
	Leaves and tops	10 tons	18.0
Total			36.3

[1] Fresh cut.

That much potassium is taken out of the soil by crops is obvious from table 2 and that some crops take out more than others is equally clear. When crop after crop is produced on the same soil and sold away from the farm in the form of grain or livestock the supply of available potassium is gradually but nevertheless surely depleted. As a result of this loss in fertility crop yields are gradually reduced until a point is reached where soils once well supplied with available potash are being farmed at a minimum profit and frequently at an actual loss unless manures and potash-containing fertilizers are employed to compensate for the losses.

SOURCES OF FERTILIZER POTASH

The principal potash fertilizer materials used commercially are potassium chloride (muriate of potash), potassium sulphate (sulphate of potash), potassium nitrate, and manure salts. All of these are high-grade potash salts, the potassium nitrate containing nitrogen in addition to potash. Of these different salts the muriate, sulphate, and manure salts are the most extensively used. Many miscellaneous sources of potash are available also, but generally speaking their potash content is too low to warrant their commercial use. They do, however, possess considerable value when used locally and wherever the expense of transporting them is not excessive. A description of the various potash fertilizer materials will be found elsewhere in this Yearbook.[3]

The question is frequently raised as to the comparative value of the different commercial potassium salts in crop production. In general it might be said that there is very little difference in their effects except in very special cases, when the accompanying constituents or accidental impurities are usually the cause.

Results of experiments over a period of years (*295a*, *360a*, *360b*) on the principal soil types of the southeastern Cotton Belt with sources of potash in mixtures with phosphoric acid and nitrogen show that there is not a wide variation in their effects on cotton yields. On 12 soil types in the Coastal Plain, potassium chloride gave an average yield of 1,212 pounds of seed cotton per acre, potassium sulphate 1,231 pounds, and kainite 1,133 pounds. On five soil types in the Piedmont, potassium chloride gave an average yield of 938 pounds, potassium sulphate 937 pounds, and kainite, 892 pounds. On all of these soils potash gave an increased yield, and on some the crop failed or was greatly reduced in growth and yield unless potash was applied.

In experiments with sweetpotatoes on six soil types (*360d*) in the large sweetpotato-growing sections of the South, potassium sulphate as the source of potash in fertilizer mixtures with phosphoric acid and nitrogen gave an average yield of 148 bushels per acre, potassium chloride 142 bushels, and kainite 94 bushels. The low yield from kainite is attributed to injury from excessive salts carried in this low potash-containing material. Sweetpotatoes require a large amount of potash. Potash salts containing low percentages of potash are not suitable for use in sweetpotato fertilizers unless precautions are taken to apply the fertilizer so as not to injure the young plants. Best results were secured with 175 to 200 pounds of potash per acre.

In experiments with celery and lettuce in Florida (*360c*) on fine sand, potassium sulphate as the source of potash in mixed fertilizers gave a yield of 511 crates and potassium chloride 574 crates of celery per acre. Potassium sulphate gave a yield of 434 crates and potassium chloride 430 crates of lettuce per acre. Potash was effective in maintaining yields of these crops on the Florida soils. On other truck crops, including cabbages, peppers, tomatoes, and strawberries, potassium-magnesium sulphate gave somewhat larger yields than potassium sulphate or potassium chloride.

Experiments on soils in the potato belt of North Carolina (*295a*,

[3] See Fertilizer Materials, p. 487.

467a) show only slight variations in yields from *different potash* sources. On Dunbar fine sandy loam potassium sulphate gave an average yield of 187 bushels per acre and potassium chloride 173 bushels. On Portsmouth sandy loam the two potash salts were equally effective in crop production. On Bladen fine sandy loam potassium sulphate gave an average yield over a 5-year period of 254 bushels per acre, potassium chloride 274 bushels, and potassium-magnesium sulphate 237 bushels. Potash increased the yields of potatoes on these soils; 80 to 100 pounds per acre gave the best results.

POTASSIUM CONSUMPTION IN THE UNITED STATES

The consumption of potassium varies widely in the different soil and crop regions. It has been estimated that in the United States as a whole about 410,000 tons of potash were consumed in 1937, more than one-half of which—218,500 tons—was used in the Southern States. The next largest consuming regions are the Middle Atlantic States with 62,700 tons and the Middle Western States with 59,400 tons. The New England group consumed 26,500 tons and the Western States 17,000 tons. These were chiefly used in complete fertilizers, the composition of which varied for different crops and soils, but with an average content of potash in the fertilizer formula of approximately 9 percent in the New England States, 6 percent in the Middle Atlantic and Western States, 5½ percent in the Middle Western States, and 4 percent in the Southern States. The estimated consumption of potash (as tons of K_2O) used in the various States in 1937 was as follows:

	Tons		*Tons*		*Tons*
North Carolina	44, 301	Louisiana	6, 941	Minnesota	838
Florida	35, 813	Tennessee	6, 462	Rhode Island	754
Georgia	33, 030	Kentucky	5, 301	Iowa	398
South Carolina	27, 644	Massachusetts	4, 369	Oklahoma	348
Alabama	27, 590	Texas	4, 335	Idaho	347
Pennsylvania	19, 705	West Virginia	3, 564	Kansas	336
Virginia	18, 335	Connecticut	3, 537	Arizona	293
Ohio	16, 634	Arkansas	3, 474	Montana	246
New York	16, 096	Missouri	3, 211	New Mexico	185
Indiana	15, 923	Illinois	3, 206	Utah	123
Maine	14, 216	Wisconsin	2, 758	Wyoming	92
Mississippi	13, 341	Delaware	2, 504	Colorado	57
California	11, 598	Washington	1, 862	Nevada	31
New Jersey	10, 951	New Hampshire	1, 319	Nebraska	16
Maryland	9, 639	Vermont	1, 271	North Dakota	14
Michigan	8, 131	Oregon	1, 045	South Dakota	4

NEED FOR AND EFFECTS OF POTASSIUM

Like nitrogen and phosphorus, potassium must be in an available form, or in other words soluble in the soil moisture, before plants can utilize it. Without sufficient available potassium in the soil crop plants suffer in reduced vigor, greater susceptibility to disease, impairment of growth processes—including assimilation of carbon dioxide—failure to develop normally and translocate starch within the plant, and in other ways equally adverse. On the other hand, the presence of an adequate supply of available potassium in the soil promotes the health and improves the quality of the plant, insures greater efficiency in photosynthesis, increases resistance to certain diseases,

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offsets the effect of an oversupply of nitrogen, and helps the plant to utilize soil moisture more advantageously, particularly during droughty spells. A plentiful supply of available potassium, moreover, insures the development of well-filled kernels in cereal grains and gives stiffness to the straw, encourages the growth of different leguminous crops, assists in the functioning of chlorophyll, and is particularly helpful in the production of starch- or sugar-forming crops.

Potassium might be considered to stand between nitrogen and phosphorus in its effects on plant growth. It tends to slow down the effects resulting from excessive nitrogen and to prevent the too rapid maturity often induced by too much available phosphorus. It is clearly evident, therefore, that the application of available potassium compounds to the soil or the employment of practices tending to make the unavailable potassium compounds of the soil available is particularly important to the maintenance of soil fertility and to the production of crops of high quality. In fertilizer mixtures potassium acts as a stabilizer to nitrogen and phosphorus.

A lack of available potassium in the soil is very likely to result in poor quality of the crop. Tubers from potash-starved potato plants have been found to be watery, contain less starch, and be of poor edible quality generally, particularly after several months' storage. A deficiency of available potash very often results in a measured bushel of wheat several pounds under weight owing to poor filling out of the kernels. This in turn affects the quality of the flour. Leaf quality of tobacco is markedly influenced by the kind and amount of potassium applied to the plants, which may attain full height but will have poor flavor and lack the free-burning quality essential to commercial requirements. Likewise it is generally recognized, as previously indicated, that available potash increases the resistance of many crops to disease. Certain diseases of the cotton plant vanished as soon as potash was obtainable and could again be used at normal rates following the shortage of the World War period.

About one-half the potash used on crops in the United States is applied to cotton. Without it, or with too small an amount, profitable cotton production is practically hopeless. This is particularly true of the general run of cotton soils in the Southeastern States. In the days when the cottonseed or later the meal was put back into the soil most of the potash extracted by the cotton crop was conserved. In more recent years cottonseed meal has been used as a valuable byproduct for stock feeding, a large share of it going abroad. This is simply a method of selling the potash of the soil, thereby making the cotton grower buy commercial potash to offset the loss.

In the case of potatoes, one of the most heavily fertilized crops in the United States, a ton or more of high-grade fertilizer to the acre is a common application in potato-producing sections along the Atlantic seaboard from Maine to Florida. Without potash in the fertilizer the well-recognized symptoms of potash hunger soon become evident and it is questionable whether much of the commercial crop could be produced without it. Tobacco, sugar beets, certain cereals, and truck crops in general, whether for canning or for consumption fresh, quickly reflect any potash shortage. While other farm crops get along on less potash than those enumerated, every crop without

exception must have some available potash if it is to thrive and produce normally.

Amounts of Available Potassium Required for Various Crops

Plants differ markedly in their content of potassium. Plants grown together in soil cultures for 56 days by Newton (*279a*) showed the following potassium content: Wheat 4.16 percent, barley 4.04, sunflowers 3.47, and beans 1.19. Plants grown together in solution cultures for a similar length of time showed the following potassium content: Barley 6.92 percent, wheat 6.73, peas 5.25, sunflowers 5.01, beans 4.02, and corn 3.87. The percentages of potassium in barley and wheat grown in culture solution are relatively high, and are followed by those of peas and sunflowers, beans, and corn. In the cases of the four crops grown in loam soil, the same order of potassium content was obtained, except that wheat was slightly higher in potassium than barley, whereas when grown in the solution barley was slightly higher than wheat. However, wheat and barley contained considerably more potassium than was found in the other plants. The feeding power of various plants for potassium is probably related somewhat to their rate of growth. Plants that grow slowly can probably utilize the less soluble forms of potassium to a greater extent than those that grow rapidly, since they have a longer time in which to absorb the potassium.

For the production of satisfactory yields of alfalfa, corn, and cereals, about 160 pounds per acre of readily available potassium are needed according to Truog (*420a*). For potatoes, tobacco, garden, and other special crops, an even greater amount may be desirable. A crop feeds on both the readily and slowly available potassium. The readily available portion should be abundant enough to supply at least 75 percent of the needs of general farm crops and practically all the needs of special crops like potatoes and tobacco.

Crop plants have been grouped by Hartwell (*149a*) according to their response to applications of potash as follows: Low potash-response crops—oats, rye, wheat, millet, and carrots; medium potash-response crops—barley, rutabagas, parsnips, potatoes, and cabbage; high potash-response crops—tomatoes, mangels, buckwheat, corn, and onions. This classification, however, is based on the experiments at the Rhode Island Agricultural Experiment Station, and it is doubtful whether it is generally applicable to all soil regions.

Hester and Shelton (*162*) have shown that the efficiency of potassium utilization by vegetable crops varied with the different soil types. A given application of potassium was less effective on Bladen sandy loam than on either Norfolk fine sand or Portsmouth loamy fine sand. Bladen sandy loam showed the highest power for fixing potassium in a state unavailable to vegetable crops. The calculated percentages of removal of the added and replaceable potassium were 38.5 from the Bladen sandy loam, 82.8 from the Portsmouth loamy fine sand, and 84.8 from the Norfolk fine sand. Such results would definitely suggest that a higher available potassium level would be required for the Bladen than for the Portsmouth and Norfolk soils.

Bryan (*54a*) has also called attention to the wide variation in the

availability of potassium in different soil types. He states that it is not necessary to have as high a level of potassium fertilization in the sandy soils of the Coastal Plain as in the soils of the Corn Belt. The potassium in sands is considered to be relatively highly available. It is possible to produce successful crops on these sandy loams at a lower potash level than would be possible in other regions where the soils are ordinarily inherently more productive. In general, it may be said that cotton growers in the Southeast have not raised the level of available potassium in their soils to the extent that is common in some of the central-western soils.

In the Southeastern States where the rainfall and temperature are relatively high, the soils have been thoroughly leached and are relatively low in available potassium. It has been pointed out that a large percentage of the total potash fertilizer used in the United States is applied to cotton and tobacco. Some of the other commonly grown field crops of this region, such as corn, small grains, and hay, produce satisfactory yields at a relatively low potassium level as compared with that required by tobacco and cotton. Where the latter crops are grown after legumes, corn, and small grains, potassium is very often the limiting factor in determining the yield. Since many of the soils in this region have a relatively low fixing power, considerable potassium may be lost in drainage if heavy applications of potassium salts are made. It is therefore often more practical and profitable to make applications immediately preceding all crops which give a marked response to potassium fertilization.

POTASH CYCLE

When a potash fertilizer salt is applied to the soil, part of the potassium is fixed in unavailable compounds. The extent of the fixation is almost always directly proportional to the content of colloidal matter in a soil, being greatest in clays and clay loams and least in light sands and sandy loams. The fixation or holding of potash by the soil is of great importance as it serves as a check against too rapid solution and leaching and makes for a more continuous supply of available potash.

Potash salts are more readily fixed than nitrogen salts but less readily fixed than the phosphates. While potash salts readily dissolve in the soil moisture they soon are taken out into less soluble forms as they unite with the colloidal complex and replace calcium or some other element associated with the finest soil particles. Potash so fixed may move slowly in the soil, the rate being dependent upon the amount and nature of the colloidal complex. In light sands and sandy loams the movement may in time carry the potash down to the ground water while in soils with high clay and silt content the movement is slow and frequently restricted to the upper 4 to 6 inches of soil.

The potash cycle is therefore a fairly simple one compared to that of nitrogen with its many transformations and its tie-up with organic matter. It is fixed by the soil; it is removed by crops and to some extent in drainage waters; it is returned to the land in crop residues or in the manure of farm animals, or it is exported in crops sold. While potassium occurs in nearly all animal tissues, there occurs no such accumulation as there is of phosphorus in bones or nitrogen in

body proteins. The potassium remains essentially soluble and passes through the animal, being excreted chiefly in urine. The cycle is therefore essentially from fertilizer to soil moisture to plant, with the soil particles acting as a regulator of solubility; then from the plant to the animal; and through animal wastes back to the soil. The losses occur through leaching, sale of crops from the land, and wastage of manures, especially the liquid portions. Such losses must be supplied in added fertilizer to prevent potash deficiency and lowered soil fertility.

THIS *article tells how crop rotation is related to soil fertility, to the control of plant diseases and weeds, and to erosion control. It gives examples of good rotations and discusses the factors that are important in planning rotations for a particular farm. Finally, it outlines the rotation systems adapted to the major farming regions of the United States, shows what the actual practices are, and suggests possibilities for modifications.*

Crop Rotation

By Clyde E. Leighty [1]

IN CONTRAST to the continuous growing of a single crop on the same land, or to haphazard cropping of the land without plan or studied design, the systematic rotation [2] of crops may have many advantages. First and foremost, perhaps, is the provision made in a good rotation for maintaining or improving the fertility of the soil. Usually this requires the growing of a legume and sod crop to promote fixation of nitrogen and maintenance of humus. As manure is exceedingly useful in maintaining fertility, abundant roughage and pasture for animals is provided by crops in the rotation. If no animals are kept on the farm, green manures and crop residues may be plowed under in place of yard and stall manures to maintain the supply of organic matter.

FACTORS CONTROLLING ROTATIONS

The determination of the crop rotation to be used on a farm involves consideration of many and diverse factors. Basic to the choice of a rotation is the farmer's desire to get the most out of his farm for the effort he puts into it. The fertility of the soil, its tilth, drainage, reaction, and slope, the temperature, rainfall, weeds, plant diseases,

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[2] "Crop rotation" may be defined as the growing of different crops in recurring succession on the same land, in distinction from a one-crop system or a haphazard change of crops determined by opportunism or lacking a definite plan. Many definitions of crop rotation given in textbooks, bulletins, dictionaries, and encyclopedias go beyond their field and tend to limit the term by defining good rotations or by bringing into the definition the attributes or purposes of a good rotation or the objects sought to be accomplished by it. Obviously a crop rotation may be good or bad in its effects on the soil and in its economic returns. In rotations, the change in crop may be annual; after several years, as with alfalfa; or after many years, as with orchards; but with most crops and soils rotation is desirable.

and insect pests determine certain limitations to the kinds and proportions of crops to be grown. Within these limits the relative prices of the products that can be produced, the labor distribution through the season, and the prices of materials and labor used in production determine more definitely the acreages devoted to the various crops and the number of each class of livestock. Personal preferences for certain crops and kinds of livestock may be important for a few years but become less so as the pressure of these other factors is increasingly felt.

Adaptation to soil types is generally recognized as an important factor in determining what crops should be grown. Very often there is considerable range in adaptation of a crop, but definite limitation for one reason or another with respect to certain soil types.

What crops should be grown and their sequence in the rotation is frequently dependent on topography. Rotations suited to level land may be entirely unsuited to steep slopes on the same farm. By use of proper rotations the liability of serious erosion may be materially decreased.

In its essentials a good crop rotation utilizes crops that are adapted to the environment and that fit into a farming system that is planned and integrated as an efficient business undertaking. Methods should be employed that will maintain or improve yields, and to this end attention must be given to (1) maintenance of soil fertility, (2) plant-disease and insect-pest control, and (3) weed control.

Diversification and Crop Conflicts

It generally pays a farmer better to have several important products rather than only one. Diversification provides against total failure, distributes the income over the year, and tends to provide year-around work for men, machinery, and horses. Diversification is accomplished best through crop rotation, as by this means maintenance of yields tends to be assured. With only one product the risk of failure due to weather, pests, and prices is much greater than with several crops, all of which are not likely to suffer from the hazards occurring in any particular year.

Seasonal distribution of labor is of first importance in determining crops that may be grown and therefore in determining what rotation may be followed. A full year's work for men and teams is generally essential for farm success. Conflicts in labor requirements of crops are frequent. Alfalfa, corn, and winter wheat seriously conflict in Kansas and Nebraska. All are good crops. When wheat is most profitable, it is grown at the expense of the other two with resulting limitation in livestock. In the Corn Belt, corn pays better than alfalfa and so is more generally grown. Corn combines well in the Corn Belt with clover and timothy hay and with oats, but not with sugar beets. When there is serious conflict between crops, the more profitable one is likely to be grown. When there is little difference in profit, two or more crops may be grown on the same farm, despite their conflict, especially when much the same equipment may be used for both.

Farm Lay-Outs

In establishing a rotation on a farm, attention to farm lay-out is of much practical importance. Fields and pastures should be so arranged that farm operations may be conducted most efficiently. Many different factors will require consideration in establishing a satisfactory lay-out. These will vary from farm to farm according to topography; permanent features, such as roads, streams, and ditches; soil variations; type of farming, crops to be grown, and livestock to be kept; size of farm; machinery to be used; location of buildings; and other conditions that will suggest themselves as the problem is studied.

The simplest and most economical lay-out is one of square fields of uniform soil and nearly equal size. In many areas, however, rough land, woodland, or other natural features may seriously interfere with such an arrangement; and the necessity of protecting the soil against erosion may make it entirely inadvisable.

Planning Rotations

Rotation of crops is necessarily based on a long-time plan. The plan itself to be sound must have back of it a fund of accumulated knowledge. This may have been accumulated by the farmer himself or by his neighbors, or it may be based on experiments conducted by experiment stations. It presupposes certain decisions by the farmer.

Within certain limits a rotation need not be inflexible. It may be varied in details from year to year as information accumulates or as conditions change. These modifications often may be made without disturbing the essential plan of the rotation, as in substituting barley for oats as a spring-sown small-grain crop. The principles of a sound rotation, however, should be followed whenever a change is made. "To simplify the planning of rotations, field crops are divided into three classes, grain crops, grass crops, and cultivated crops" (*154*).[3] Bare summer fallow, as practiced under semiarid conditions, may be regarded as a cultivated crop. Bearing in mind this classification, considerable elasticity may be allowed in carrying out a definite or fixed rotation without interfering with its purposes.

It may sometimes be desirable to make a radical change in a rotation, involving change even in the type of farming being practiced. As a rule such radical changes are made reluctantly by farmers, who are apt to proceed too slowly rather than too suddenly or too fast. The improvement in agriculture that followed the eventual adoption of the enclosure system in France, as also in England, was marked. Crop yields were increased manyfold as a result of the gradual increase in soil fertility that came about through the better methods, which farmers in the beginning bitterly opposed.

The demand of consumers for farm products on the one hand and the supply of the various products that farmers can produce profitably at prevailing prices on the other have resulted in a variety of crop rotations for different parts of the country. In some areas crop rotations have changed little in recent years. In other areas changes

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181. Other publications dealing with the subjects in this article but not specifically referred to are: (*10, 24, 34, 43, 50, 119, 151, 169, 194, 205, 206, 207, 208, 225, 262, 264, 272, 286, 288, 330, 348, 357, 358, 372, 396, 408, 441, 456, 475*).

are still taking place. During the past 10 years, for example, the proportion of potatoes to other crops has increased greatly on many farms in central New Jersey, owing to improvements in tractors, potato machinery, improved seed, spraying, and fertilizer practices. Similar conditions have stimulated an increase in the proportion of potatoes grown on farms in Aroostook County, Maine. Wheat production in the Great Plains States was greatly stimulated by improvements in tractors, combines, and certain tillage machinery.

Example of a Good Rotation

Some of the essentials of a good rotation are illustrated by one practiced by many farmers in the Northeastern States. This is a 5-year rotation of corn, oats, wheat, and 2 years of clover and grasses.

Farmers practicing this rotation usually feed the corn and oats and most of the hay to cattle and sell dairy products, wheat, and some hay and livestock. The growing of wheat and hay as cash crops distributes the risk much better than if dairy products were the only source of income. Pasture for livestock may be provided by the clover and grasses, but permanent pasture is often available on land unsuitable for cultivation. It may be necessary to buy some feed and grain concentrates.

The cultivated crop, corn, controls weeds and uses manure effectively; it provides both grain and stover for feed, or the entire crop may be used for silage. The 2 years of clover and grass in the rotation provide hay and pasture, and are of benefit to the soil through the addition of nitrogen and organic matter. Wheat is a good nurse crop for the clover and grass.

Manure produced by the livestock, when handled properly, helps to maintain fertility and to reduce expenditures for commercial fertilizers, as does the use of legumes in the rotation. Manure is usually applied preceding corn, but some of it may be used on the meadows. Fertilizers may be used with oats, wheat, and grass.

Oats may often be sown on disked cornland. With disking of the cornland, plowing is necessary only twice in 5 years, in preparation for corn and wheat. In more southern areas, however, it is desirable to grow a cover crop on the land during the winter to prevent leaching of soluble plant foods. This necessitates one more plowing, but benefits from the crop overbalance this cost.

RELATION OF CROP ROTATION TO SOIL FERTILITY

Various factors are concerned in the maintenance of soil fertility. These include drainage, irrigation, organic matter, crop residues, farm manures, cover crops, soil reaction, liming, fertilizers, tillage, and crop rotation. Generally speaking, less thought is given to the benefits accruing from crop rotation than to those from some of the other factors. This is probably owing to the fact that farmers practicing crop rotation have no direct means of visualizing its beneficial influences, whereas the use of manure, lime, or fertilizer is as a rule reflected in an appreciable increase in crop growth and production. The increased yields resulting from the practice of systematic crop rotations is well illustrated by the experimental work of a number of the State agricultural experiment stations (fig. 1).

Among the outstanding advantages of crop rotation from a soil-fertility standpoint are: (1) It keeps soil in suitable physical condition; (2) it helps to maintain the supply of organic matter and nitrogen in the soil; (3) it provides a practical means of utilizing farm manure and fertilizer; (4) it keeps the soil occupied with crops; (5) it changes the location of the feeding range of roots; (6) it counteracts the possible development of toxic substances; and (7) it improves crop quality.

The rapid loss of the soil organic matter resulting from growing the same crop continuously has a distinctly bad effect on good tilth. Loss of organic matter from sandy soils has a tendency to make them looser and subject to leaching; and the clays, clay loams, and loams lose their crumb structure, becoming much less easily plowed and cultivated and more easily puddled into hard lumps if plowed or otherwise worked when too wet. The importance of preventing such a soil condition cannot be overemphasized. The growing in rotation of suitable crops—grass, pasture, and deep-rooted legumes—on soils inclined to puddle is essential to maintain the soil organic matter and with it proper tilth. A rotation that includes a sod crop helps to maintain the organic matter supply of the soil and furnishes raw food material for soil bacteria.

By alternating shallow-rooting with deep-rooting crops, different soil horizons serve as feeding ranges, which has a tendency to prevent the exhaustion of available plant food in localized areas. Deep-rooted plants, such as clover and alfalfa, alternating with shallow-

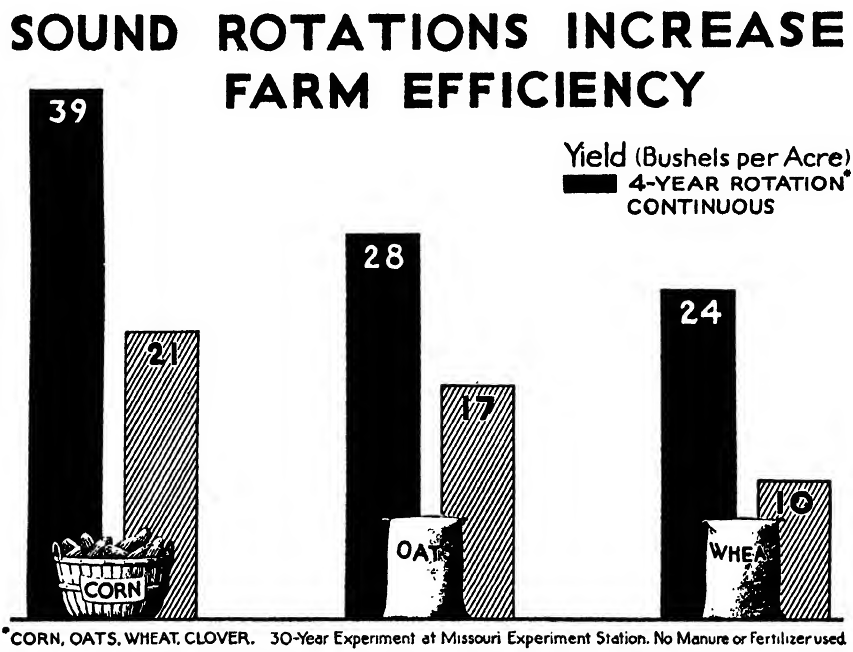

FIGURE 1.—Average yields of corn, oats, and wheat in a 4-year rotation and continuously cropped at the Missouri Agricultural Experiment Station.

rooted crops, improve the physical condition of the soil and subsoil. Deep root penetration on the part of certain leguminous crops not only provides better drainage, resulting from channels left after the roots decay, but effects a withdrawal of plant-foot elements from lower depths and leaves root residues to help maintain the organic matter and plant-food content of the soil.

Well-arranged systems of crop rotation make practicable the application of manure to the most responsive crops or to those crops that have a long growing season or a high money value. The use of manure is also indicated on crops that are rated as gross feeders, such as corn. Where manure is lacking, the same practice applies to the use of commercial fertilizer. Fertilizers are best applied to the cash crops. For example, in a rotation of corn, oats, wheat, and mixed hay (clover and timothy), the corn and wheat are fertilized, the oats and hay having to depend on any residual fertilizer. In such a rotation, manure, if available, would be applied to the cornland.

Crop rotation, in contrast with continuous cropping, makes it possible to have the land occupied with a suitable crop most of the year. The loss of plant food by leaching is minimized, and losses from soil erosion are greatly reduced as compared with unoccupied land.

The growing of one crop year after year may lead to the development of certain organic toxic compounds resulting from improper decomposition of soil organic matter. Crop rotation insures normal decomposition processes and thereby affords a practical means of preventing the formation and accumulation of injurious substances in the soil.

Crop rotation not only tends to favor higher crop production, but as a rule insures better crop quality than continuous cropping. There are numerous cases on record to show the advantageous effects of rotating crops on yield and quality. The fact that the ravages of insect pests and of plant diseases are reduced to a minimum in a crop-rotation system as compared with continuous cropping is an insurance for better crop quality. In many instances the chief emphasis so far as quality is concerned has been placed upon the cereal crops. Quality factors in these crops involve chiefly test weight per bushel, plumpness of kernel, and protein content of the grain, all of which are generally improved as the result of rotation. The beneficial influences of crop rotation and any soil treatment supplementing it are important factors in hastening the maturity of crops. This is particularly true of corn, which is susceptible to early frosts.

In considering the advantages of a systematic crop rotation, it is evident that when compared with continuous cropping a rotation system helps to maintain soil fertility and frequently increases it, but it should not be depended upon entirely to do so. Rotation of crops is one thing. The use of manure and fertilizer is another. By combining the two intelligently, best results have been obtained and soil fertility more adequately maintained at a high level. The rational use of manures and commercial fertilizer in conjunction with crop rotation will prevent soil depletion much more effectively than rotation alone. This is well borne out by the long-time rotation studies of the Illinois Station, as reported by DeTurk, Bauer, and Smith (*91*).

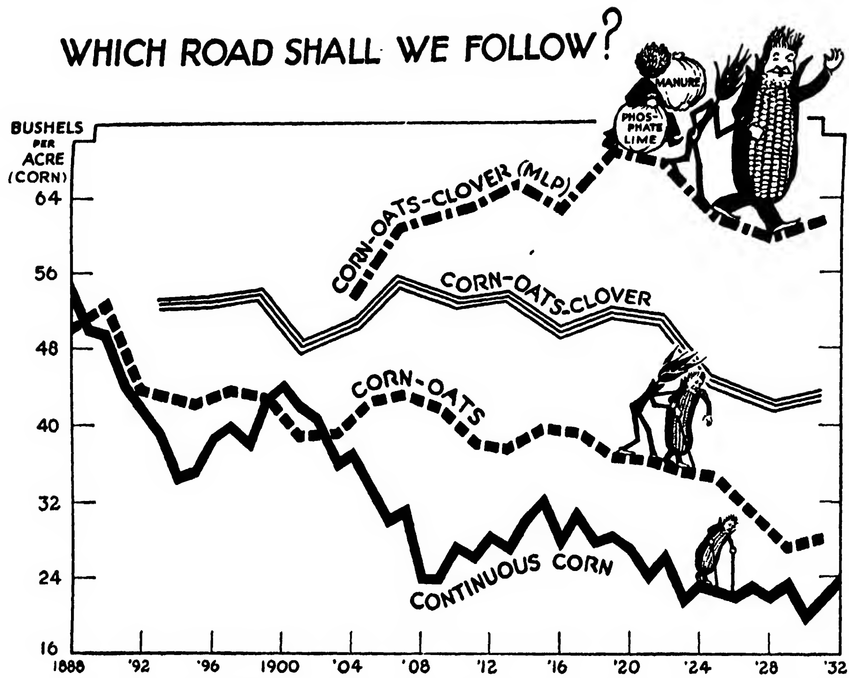

FIGURE 2.—Yields of corn grown continuously; corn grown in a 2-year rotation of corn and oats; and corn grown in a 3-year rotation of corn, oats, and clover, with and without fertilizer, on the Morrow field plots of the University of Illinois.

The practical results of these studies are illustrated in figure 2.

Not only is it true that crop rotation plus proper fertilizer treatment tends to maintain the organic matter and nitrogen content of the soil; it also tends to maintain the activities of soil bacteria at a high degree of efficiency, which in turn is reflected in an increased supply of available nitrogen, as nitrates, and a better opportunity for the mineral plant-food constituents to be rendered available to plants.

LEGUMES IN ROTATIONS

The growing of legumes in the cropping system is widely recognized as useful in the maintenance of fertility. But some legumes, like soybeans and cowpeas when harvested for hay, may be grown in regular order in a rotation with little or no benefit to the land through addition of nitrogen, which is the only element added by legumes. Other elements such as potassium and calcium may be decreased even more rapidly by some legumes than by some nonleguminous crops.

Experiments in Kentucky (*310*) showed that clover was greatly superior to soybeans in the maintenance of nitrogen, when both crops were harvested for hay. Soybeans drilled solid were more effective in nitrogen conservation than when drilled in rows and cultivated. Clover also had greater residual effect than soybeans. Hay yields

were about one and a half times as large from soybeans, however, as those from clover in comparable tests. Clover would probably have less advantage, then, if all manure from feeding the hay were saved and returned to the land.

A comparison of the yields of wheat and corn following legumes turned under, legumes harvested for hay, and nonleguminous crops is shown in figure 3, which was drawn from data presented in Virginia Agricultural Experiment Station Technical Bulletin 19 (*165*). In this case the inclusion of a legume increased the yield above that of rotations not containing a legume, even when the nonleguminous crop (rye) was turned under. Turning under the legume still further increased the yield.

A 1-year cropping system has been devised and used successfully for several years in Missouri in which Korean lespedeza is grown following a small-grain crop each year. Wheat, oats, barley, and rye used in this way may be harvested for grain or used for hay or pasture. The lespedeza following the grain crop may be used during the summer for hay, seed, or pasture. The land may bedisked in preparation for grain seeding. Where seeding may be delayed in the fall until the lespedeza seed is mature it will reseed itself year after year; otherwise sowing of the grains in the early spring will be necessary.

This system has several advantages. As a legume is grown every year, it is useful in improving poor land. The land is protected from erosion by a growing crop the entire year, except for a few weeks after seeding the grain crop. The system thus may be used to advantage on rather steep land. It may be used on single fields where a

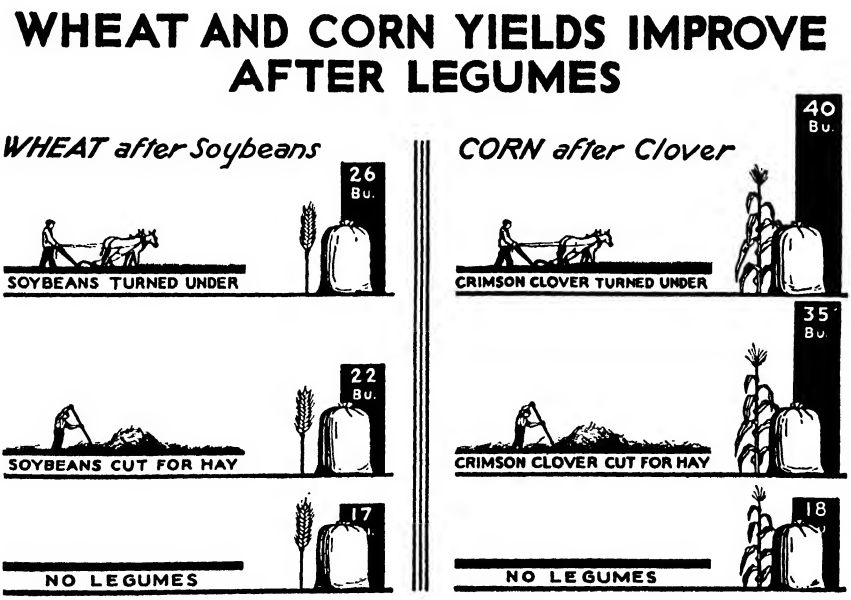

FIGURE 3.—The 7-year average yields of wheat and corn following legumes turned under, legumes harvested for hay, and nonleguminous crops at the Virginia Agricultural Experiment Station.

longer rotation might not be applicable, and it may be readily shifted from field to field. Both the grain and the lespedeza may be utilized in any one of three ways—harvested for grain or seed, pastured, or cut for hay.

It is well understood that legumes to be effective as nitrogen gatherers must be inoculated with their proper organisms. A further characteristic of legumes is that even though they are properly inoculated they fix nitrogen from the air only to the extent that the supply in the soil is insufficient for their needs. In a soil where the nitrogen content is low, then, the legumes are more effective in gathering nitrogen. This would indicate that the legume crop in the rotation should not follow the crop to which manure is applied, because not all of the manure is likely to be used by this crop and its remnants will tend to reduce the activity of nitrogen-fixing organisms. If two or more crops intervene after application of manure and before the legume is grown, the latter will be more effective as a nitrogen gatherer.

In consideration of legumes in rotations, not only fixation of nitrogen but also its utilization and its conservation are of importance. Even when considerable nitrogen is gathered by the legume, much of it may be lost from the soil in common farm practice, and therefore full benefit from growing the legumes often is not realized. These losses may come about through nitrogen being leached into the subsoil out of the reach of plant roots or being carried away in run-off water. In order to avoid these losses the crop rotation and the practices in growing crops must be designed with this purpose in mind.

The annual legumes, whether harvested or not, should be followed by fall-sown grain—wheat or rye in northern areas, or wheat, rye, barley, or oats farther south. These crops will take up much of the soluble nitrogen and prevent its loss by leaching. Unless these grains are sown quite early, they will not make sufficient growth in the fall to utilize all the nitrogen. But such plantings are always advisable either for grain production or as catch crops for plowing under the following spring in preparation for other crops, for in addition to nitrogen conservation the grains serve a useful purpose in minimizing soil erosion during the winter.

CROP ROTATION IN RELATION TO THE CONTROL OF PLANT DISEASES

Crop rotation has been advised for the control of many plant diseases. In some instances the most effective known control measure is rotation combined with seed treatment and general sanitary measures, but these methods are of little or no avail in the case of many diseases.

Certain parasites remain from season to season in the soil, living on plant refuse from the previous crops or coming from other sources, and when susceptible crops are grown every year the parasites tend to accumulate to a point which makes production unprofitable. It is for this group of parasites that crop rotation has made the best showing as a control measure. However, it should be emphasized that in most cases the efficiency of rotation as a control measure depends on using clean seed, seedlings, or bulbs, and following field-sanitation measures. In table 1 will be found the outstanding examples of diseases that can be so controlled and condensed notes on procedures.

Table 1.—*Plant diseases that are controlled entirely or in part by means of crop rotation, with notes on procedures*

Disease	Chief crop plants affected	Causal organism	Years crop is on and off land: On	Years crop is on and off land: Off	Resistant or immune crops which may be used	Remarks
			Number	*Number*		
Scab of cereals	Wheat, barley, rye, corn.	*Gibberella saubinetti* (Mont.) Sacc.	1	1–2	Oats, soybeans, clover, alfalfa, flax.	In badly infested areas wheat, barley, rye, and corn should not be grown in any sequence within the group. Crop refuse should be burned or plowed deeply. Use clean seed. Use resistant varieties where available.
Flag smut	Wheat	*Urocystis tritici* Koern.	1	1	Any crop except susceptible wheat.	Resistant varieties of wheat available.
Diplodia disease	Corn	*Diplodia zeae* (Schw.) Lev.	1	1–2	Any crop except susceptible corn.	Crop refuse should be burned or plowed deeply. Use clean seed. Resistant varieties of corn available.
Nematode disease	Wheat, rye	*Anguina tritici* (Steinbuch) Filipjev.	1	1	Any crop except rye, wheat, and species closely related to wheat.	Use clean seed.
Wilt	Alfalfa	*Phytomonas insidiosa* (L. McC.) Bergey et al.	3–4		Any crop including alfalfa	Alfalfa can follow alfalfa. The point is to maintain short stands.
Stem nematode	Alfalfa, red clover	*Ditylenchus dipsaci* (Kuhn) Filipjev specialized strains.		2	Any cultivated crop	
Black rot	Sweetpotatoes	*Ceratostomella fimbriata* (Ell. and Hals.).	1	3–4	Any crop other than sweetpotatoes.	Seed and seedbed must be free of parasite.
Foot rot	do	*Phenodomus destruens* Hart	1	2–4	do	Do.
Scurf	do	*Monilochaetes infuscans* Hals.	1	3–4	do	Do.
Anthracnose	Beans	*Colletotrichum lindemuthianum* (S. and M.) Bri. and Cav.	1	2	Any crop other than beans	Use clean seed.
Blight	do	*Bacterium phaseoli* E. F. S.; *Bacterium medicaginis* var. *phaeseolicola* (Burk) Link & Hall.	1	2	do	Do.
Wilts	Potato, tomato, egg plant.	*Verticillium* spp. and *Fusarium* spp.	1	3–5	Small grains, grass, corn, and legumes.	Especially recommended in Oregon. Use resistant tomato seed.
Bacterial canker	Tomato	*Aplanobacter michiganense* E. F. S.	1	2	Any crop other than tomato	For Utah. Use clean seed.
Anthracnose	Cucumber	*Colletotrichum lagenarium* (Pass.) E. and H.	1	2	Any crop other than cucumber, muskmelon, watermelon, and gourd.	Use clean seed.
Bulb rot	Onion	*Fusarium* spp.			Any crop other than onion	Use bulbs free from parasite.

Table 1.—*Plant diseases that are controlled entirely or in part by means of crop rotation, with notes on procedures*—Con.

Disease	Chief crop plants affected	Causal organism	Years crop is on and off land: On	Years crop is on and off land: Off	Resistant or immune crops which may be used	Remarks
			Number	*Number*		
Texas root rot	Cotton	*Phymatotrichum omnivorum* (Shear) Duggar.	2-3	3-4	Grain sorghum, corn, small grains, and grasses.	Refuse plowed under deeply.
Nematode root knot	do	*Heterodera marioni* (Cornu) Goodey.	2-3	3	Alfalfa	Upland cotton in irrigated district of California.
			3	3	Sorghum, small grains, and alfalfa.	Pima cotton in irrigated district of Arizona.
Black shank	Tobacco	*Phytophthora parasitica* var. *nicotianae*.	1	4	Any common crop other than tobacco.	Method recommended for western North Carolina, but not for Florida. Seedbed must be free of parasite.
Black root rot	do	*Thielariopsis basicola* Zopf	1-2	5-6	Grass crop and weeds	Resistant varieties of tobacco are available. Seedbeds must be free of parasite.
Granville wilt	do	*Bacterium solanacearum* E. F. S.	1	3-4	Corn, small grains, forage grasses, cotton, and sweetpotatoes.	Seedbeds must be free of parasite. Many weeds harbor the parasite.
Nematode root knot	do	*Heterodera marioni* (Cornu) Goodey.	1	2-3	Peanuts, velvetbeans, Crotalaria, native weeds, cereals, and forage grasses.	Seedbeds must be free of nematodes. This parasite attacks over 500 plant species.
Sugar-beet nematode.	Sugar beets	*Heterodera schachtii* Schmidt	1	5-6	Alfalfa, sweetclover, beans, peas, potatoes, cereals, and vegetable crops.	Avoid all types of beets and crucifers such as cabbage, turnips, cauliflower, rape, etc. Many weeds are hosts for this nematode. Small grains should be confined to long rotations and not immediately precede sugar beets. The length of the rotation depends on the severity of the infestation.
Damping off "black root."	do	*Pythium* spp. *Rhyzoctonia* spp	1	4-5	Corn, potatoes, and other cultivated crops.	Sugar-beet stands are poorer when this crop immediately follows clover, alfalfa, or sweetclover.
Leaf spot	do	*Cercospora beticola* Sacc.	1	4-5	do	Fungus remains alive in refuse from preceding crop for at least 3 years.

The brown root rot of tobacco in northern areas, the cause of which is uncertain, is unique in that it is controlled most effectively in the field with continuous tobacco culture. Corn and other grasses in the rotation have increased the difficulties with this disease. A seedling damping-off disease of alfalfa caused by *Pythium* spp. increases in soil which is in fallow. When the infestation is not too bad the alfalfa is seeded very thickly.

Some soil-inhabiting parasites are exceedingly refractory to rotation and sanitary measures, as for example the vascular fungi (*Fusarium* spp.) which attack sweetpotatoes, peas, and beans; the white rot organism (*Sclerotium ceptivorium* Berk.) of onion; the club root organism (*Plasmodiophara brassiceae* Wor.) of cabbage and related plants; the flax wilt parasite (*Fusarium lini* Bolley); and the root and stem parasite (*Sclerotium rolfsii* Sacc.), which attacks a wide range of plants in the Southern States.

Rotation is of no avail in the control of such diseases as the cereal rusts, mildews, most of the cereal smuts, and potato late blight. In all of these the spores of the parasites are readily carried by the wind from infested to noninfested fields.

CROP ROTATION AND WEED CONTROL

Rotation of crops, when accompanied by care in the use of pure seed, is the most effective means yet devised for keeping land free of weeds. No other method of weed control, mechanical, chemical, or biological, is so economical or so easily practiced as a well-arranged sequence of tillage and cropping. Not all weeds can be controlled by crop rotation, nor are all one-crop farms weedy. Nevertheless, weed problems are likely to be least severe on farms where crop diversification is practiced and most severe on farms devoted for one reason or another to a single crop.

Of about 1,200 species of plants commonly called weeds in the United States, less than 30 are sufficiently aggressive to be able to survive indefinitely on crop-rotated land. These are the superweeds, the so-called noxious species, plants having such extreme tenacity of life that no ordinary good farming measures control them. They include such notorious pests as Canada thistle, quackgrass, bindweed or wild morning-glory, Johnson grass, hoary cress, nutgrass, leafy spurge, and wild onion. All of these are perennials, with spreading or creeping root systems or with underground parts, such as bulbs, uninjured by tillage. A few annuals, notably wild oats and crabgrass, are so resistant to extermination that they may be classed as noxious.

Weeds, aside from the noxious species, are not a serious problem on a well-organized diversified farm. Indeed, there is little excuse for such a farm to be weedy. Most weeds are annual plants, unable to sprout from their roots, and depend upon their seeds for reproduction. Cutting them off close to the ground before the seeds ripen destroys them. In a rotation of cultivated crop, grain crop, and meadow several opportunities occur to do this. At worst the rotation can usually be shifted slightly to throw it out of balance with the weed and cause a tillage or a mowing operation to come at a time when it will do the weed the most harm. These are facts well known to all careful farmers.

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A fact not usually so well understood is that weeds may sometimes be more valuable than harmful. Too clean tillage is often the cause of destructive soil erosion, and much good soil has been washed into the rivers because of a mistaken insistence on destroying every weed. Leaving a soil cover of not-too-large weeds may well be an excellent practice on rolling land. In any case, weeds have some value as organic material to be plowed under. A balance between too many weeds and too few weeds is probably a good objective if it can be arranged.

Among the common crops, alfalfa is the one best suited to compete with noxious weeds. The frequent cutting and heavy growth of alfalfa prevent weeds from going to seed and reduce their vegetative vigor. The weeds may not be killed by the alfalfa, but they are usually subdued sufficiently so that other crops can be grown for several years without too much interference. On severely infested land the weeds should be weakened by a month or two of fallow before alfalfa is planted.

The list of other good competitive crops is limited. Winter rye and winter wheat are often recommended for bindweed land because they provide intervals in midsummer for fallowing and make their own growth during the season when the weed is inactive. Sorghum, soybeans, and Sudan grass have been successful on infested land, although pretillage, especially in the drier areas, is often required for best results and pays well in increased yield of the crops.

Contrary to a widely held belief, fallowing for weed control need not be so frequent that all top growth is prevented. Permitting the weeds to make a few inches of growth between cultivations appears to weaken rather than strengthen them. Thus, cultivating every 2 weeks is as effective in killing bindweed as cultivating once a week. A combination of this kind of tillage with crops like alfalfa and winter wheat appears to be the most economical and effective rotation yet known for reducing serious infestations of the more persistent weeds.

On a large scale, weeds tend to become a very serious matter in grain-growing regions of the West. In most spring wheat areas there is little choice of crop, and the only recourse is to alternate grain growing with summer fallow. Even this does not control such hardy species as Russian-thistle. Although weed control is not the primary purpose of summer fallow, it may often be an important consideration.

In some kinds of one-crop farming, weeds, while plentiful, do not prevent the production of good yields. A notable example is the southeastern Cotton Belt, where cotton is traditionally the principal if not the only crop grown. Left to themselves the cottonfields would consist almost wholly of masses of crabgrass by the middle of summer. The only thing that makes cotton growing possible is the fact that the cotton is chopped, or hoed, often several times during the season. The first chopping must be done to thin the stand, and in doing this the worst of the young crabgrass is removed. The introduction of diversified farming in the South in which cowpeas, soybeans, or other crops that smother the weeds are grown, might, in addition to other benefits, reduce the stand of crabgrass, thereby reducing the

amount of hand work and as a consequence materially lowering the cost of production in this hard-pressed industry.

CROPPING SYSTEMS AND EROSION CONTROL

Susceptibility to erosion is an important factor in determining the kind and sequence of crops that should be grown on any particular piece of land. Erosion may result from action of either wind or water. That by wind is seldom serious except in dry-land areas such as the Great Plains. Erosion by water may occur anywhere that water moves over the land and is greatest and most damaging in areas of high rainfall and steep slopes.

The amount of erosion by water is influenced by the texture, structure, and organic-matter content of the soil. It may be modified by methods used in handling the soil and by the cropping practices employed. On lands subject to excessive erosion on account either of their slope or the character of their soil, cultivated crops such as corn, cotton, and tobacco subject the soil to destructive hazards. For example, on deep and fertile lands adapted to corn, this crop may have a prominent place in the rotation where the slope is slight. As the slope increases, corn should give way more and more to the small grains and sod crops and may finally, on steep slopes, need to be replaced entirely by protective crops or even by trees.

The same principles apply to other crops that are grown in rows and that are cultivated during their early growing season. This period is generally one of high rainfall, and the cultivation is chiefly for the purpose of destroying weeds and grass that compete with the crop, but which would protect the soil from erosion if left to grow. The cultivation itself fines the soil and puts it in condition to be easily washed away. Corn and the cultivated crops generally are soil destroyers, unless they are kept in their places by proper rotation.

A study made at the Missouri Agricultural Experiment Station (*261*) gave the results shown in table 2, which show strikingly how a good crop rotation reduces soil losses.

Table 2.—*Average of 14 years' measurements of run-off and erosion at the Missouri Agricultural Experiment Station*

[Soil type—Shelby loam; length of slope, 90¾ feet; degree of slope, 3.68 percent]

Cropping system or cultural treatment	Average annual erosion per acre	Run-off of rainfall	Cropping system or cultural treatment	Average annual erosion per acre	Run-off of rainfall
	Tons	*Percentage*		*Tons*	*Percentage*
Bare, cultivated, no crop	41.0	30	Rotation—corn, wheat, clover	2.7	14
Continuous corn	19.7	29	Continuous bluegrass	.3	12
Continuous wheat	10.1	23			

The prevention of loss of water by run-off, as shown in these experiments, is of especial significance for areas of limited rainfall or those subject to occasional drought. Where rotation was practiced the loss of water was less than half the amount lost from bare land and from land in continuous corn, about two-thirds that from land in continuous wheat, and only one-sixth more than from bluegrass sod. This

emphasizes the benefit of a suitable crop rotation in promoting greater efficiency in water conservation as well as in improving the soil.

With devices for controlling erosion, such as terracing, contour farming, and strip cropping, the question of crop rotation will require specific consideration in order to fit the cropping system into the plans adopted and the devices used. Rotations themselves may or may not need to be changed from those already practiced, but certain modifications often will be necessary. In strip cropping, especially, the kind and sequence of crops to be grown on the narrow strips established on sloping land will require careful planning, so that thick-growing crops, such as clover and wheat, will alternate with cultivated crops in successive strips up and down the slope. With strips following the contour, some irregular areas may need to be kept in permanent grass in order to avoid point rows. It will be difficult to utilize these grassed areas for pasture on account of the fencing involved. This will also be true to a greater or lesser extent for the entire stripped area. Considerable trying out of crops and methods will be required before proper rotations for strip cropping are fully worked out.

In dry-land areas where soil blowing must always be guarded against, strip cropping is being increasingly utilized as a protective device. In its simplest form and where most used in the northern United States and in the prairie Provinces of Canada, strips of grain are alternated with strips of summer fallow or corn. The following year the position of the crops is reversed. The grain stubble protects one strip while the other is in fallow, and the fallow strip is so narrow that blowing does not gain much headway. Very little is known regarding the adaptation of this method to other parts of the dry-land area. Growing corn or sorghums in strips alternating with wheat in other areas may favor injury by insect pests such as chinch bugs and grasshoppers, which migrate from one crop to another.

ROTATIONS USED IN THE UNITED STATES

There are no specific data on rotations practiced in this country as a whole. Many of the rotations practiced on individual farms, and rotations common in general areas, however, are known. It is certain that the combinations of crops into rotation systems are numerous and for the whole country very diverse.

In spite of the many different rotations practiced and the fact that no one rotation can be considered as typical, certain crops and systems of cropping tend to predominate in different sections of the country. Each principal type of farming region in the United States has one leading crop around which rotations and livestock production (if any livestock-production system can be used to advantage) are built up.

Some of the principal regions and the rotations practiced in them will be considered here, including the Corn Belt, the Cotton Belt, the dairy region, the wheat region, the dry-land area, and the irrigated sections.

Crop Rotation in the Corn Belt

A desirable rotation is one having the greatest net value over a period of years. Corn is the most valuable crop grown on practically all the farms in the Corn Belt. Therefore, the rotation of crops should be centered around corn. As much corn should be included in the rotation as is consistent with the maintenance of high acre yield and soil fertility and with the effective utilization of labor and equipment.

The particular rotation that should be chosen on an individual farm will depend on which one of many influences is a limiting factor in a given situation. The recommended proportion of corn in the rotation is usually determined by the

fertility of the soil, although the seasonal labor peaks at planting or harvest time may sometimes be more important factors. Corn and oats fit together almost perfectly from the standpoint of seasonal labor requirements, but oats usually have a much lower value per acre than corn. Soybeans compete with corn for labor and power but have a higher acre value than oats. The increased use of tractors for power has leveled off somewhat the spring labor peak that would have been caused by increasing the acreage of soybeans.

The value per acre of a specific crop must very often receive only secondary consideration in planning a rotation of crops. The oat crop may be less valuable per acre than any other crop grown, but it is usually necessary as a nurse crop for legume sod crops, which tend to maintain the yield of corn. Even the legume sod in the rotation is often justified more by its influence in maintaining corn yields than by its direct value for hay or pasture.

Sometimes cropping practices must be changed to make possible the effective use of a given rotation. Where clover seedings have become less certain year by year, it may be advisable to apply ground limestone or phosphate before increasing the acreage of clover and timothy which would otherwise consist largely of timothy. The use of a hybrid seed corn that is known to produce stalks less susceptible to breaking over may remove the principal difficulty in seeding winter wheat in the standing corn and thus make possible a corn-wheat-clover rotation.

There are ample statistics relating to the proportion of crops grown in various parts of the Corn Belt, but there is only fragmentary evidence concerning the way in which crops are rotated on individual farms. In a 3-year study made in central Indiana, the prevalence of rotations used was approximately as follows (*71*):

Rotation	Percent	Rotation	Percent
Corn, wheat, clover	30	Corn, soybeans, wheat, clover	9
Corn, oats, clover	27	Corn, corn, soybeans, wheat, clover	4
Corn, corn, oats, clover	14	Mixed rotations	3
Corn, corn, wheat, clover	4		
Corn, corn, oats, wheat, clover	2		
Corn, oats, wheat, clover	7	Total	100

Classified by percentage of corn in rotation, the following distribution is obtained:

	Corn in rotation (percent)	Land (percent)
	50	18
	40	6
	33	57
	25	16
Total or average	37	100

These rotations represent the plans rather than the accomplishments on the farms studied. This sample of 100 farms represented farms that were more efficient than the average in central Indiana. With rotations being used in the proportion indicated, the average proportion of crops in rotation would be as shown in table 3, in which these percentages are compared with the actual proportion of crops grown on 362 farms in central Indiana in 1 of the 3 years.

Table 3.—*Percentage of rotated land on 100 farms in central Indiana as calculated from frequency of planned rotations and as recorded in farm records at end of 1930*

Crop	As calculated from frequency of planned rotations	As recorded in farm records at end of 1930	Crop	As calculated from frequency of planned rotations	As recorded in farm records at end of 1930
	Percent	*Percent*		*Percent*	*Percent*
Corn	35	37	Clover and alfalfa	30	19
Oats	15	16	Miscellaneous crops		4
Wheat	17	17	Total	100	100
Soybeans	3	7			

The principal difference between the planned rotations and the achieved results was in the proportion of the rotated acreage in legume sod. On the farms studied from 1929 to 1931, 92 percent of the wheat and 78 percent of the oat acreage were sown with clover and alfalfa. These figures suggest a 3-year average clover failure of 33 percent. It is also indicated that most of the land on which clover seedings failed was planted to corn and soybeans with a slight increase in oats and miscellaneous crops.

In the central Indiana area, soil adaptation and method of harvesting corn are the principal factors determining whether wheat or oats are used in a 3-year rotation. The use of a corn-wheat-clover rotation is more nearly general in a locality where the soil is better adapted to wheat than to oats and where the corn is usually cut and shocked. On another large group of farms, the wheat is ordinarily sown in the standing corn. In the latter case a part of the cornland is usually seeded to oats.

For several reasons, more than one rotation is often used on the same farm. Variation in the type of soil or slope of the land may dictate a different percentage of corn on one part of the farm than on another part. On some farms where the crop is hogged off, one field is planted to corn continuously for a much longer period than is called for by the regular rotation. The desire for a field of alfalfa close to the buildings may alter the rotation of crops for a few fields. Convenience in the pasturing of livestock is another reason for having a minor rotation of small fields near to the buildings, even though it sometimes means an additional expenditure for fencing.

On the fertile soil of north-central Iowa, corn is grown on a much larger proportion of the rotated land than in the central Indiana area for which sample crop rotations have been given. In a 4-year study made in Webster County, Iowa, the following crop sequences are listed (*170*):

Crop sequence	Percent of acres
Corn, oats	46
Corn, corn, corn, oats	24
Corn, corn, oats, clover	5
Corn, oats, clover	4
Corn, oats, pasture, pasture	3
Alfalfa 2 or more years	2
Other sequences	16
Total	100

On about one-half of the rotated land 50 percent was in corn each year, and on an additional one-fourth of it 75 percent was in corn each year. The proportion of hay and pasture crops is much too low in this area to maintain the yield per acre of corn even on the fertile Webster loam common to the area.

In some areas in the southern part of the Corn Belt, the percentage of the rotated land in corn seems very low, but the sequence of crops indicates an exhaustive cropping system. A typical crop sequence in parts of northern Missouri includes corn for 3 years, small grain 1 or 2 years, and seeding to a mixture heavy with timothy, which remains 5 or 6 years. At about the time that bluegrass should be getting well established it is usually broken up again for corn.

The cropping system usually affects the number and kind of livestock more than it is affected by them, but there are some instances where livestock management influences the kind and proportion of crops grown. A dairy herd may require a larger quantity of high-quality roughage than a beef herd. If the crops that are grown are fed to livestock and the crop residues and manure are spread on the cropland, a higher percentage of corn in the rotation may be justified than if the crops are sold off the farm.

The availability of certain kinds of farm equipment may also have some influence on the kinds of crops grown. The big expansion in acreage of soybeans for grain came only after a large number of combined harvester-threshers were available. Some farmers have rented additional cornland because an efficient two-row corn picker enabled them to meet the seasonal peak of labor requirements at harvest time. The more flexible daily capacity of tractors has also been very instrumental in reducing the number of days to perform the peak power load and has made possible certain combinations of crops that could not have been handled economically with horse power.

Crop Rotations for the Cotton Belt

For the purposes of maintaining soil fertility, preventing ersoion, and controlling weeds, insect pests, and plant diseases, the need for effective crop rotations probably is greater in the Cotton Belt than in any other part of the country. However, definite crop rotations or crop sequences are much less common on cotton farms than on farms on which a more general type of farming is followed. Many cotton farmers follow a more or less definite cropping system, but no data are available to indicate the usual sequence in which the various crops are grown or to what extent a practice prevails in any particular section.

There are several reasons why cotton farmers generally do not follow a more definite system of crop rotation. Cotton normally occupies a larger percentage of the cropland than any other crop, frequently more than half of the entire harvested crop acreage. This is not only because cotton is the most valuable crop grown, but also because the small number of livestock kept on most cotton farms makes the acreage required for the production of feed crops relatively small. Because of these conditions the cropping system on a typical cotton farm on which the soil is relatively uniform as to productivity and crop adaptation usually consists of 1 year in corn or an annual hay crop, or both, and from 2 to 4 years in cotton. Under a cropping system of this kind the corn may or may not be interplanted with cowpeas, soybeans, or velvetbeans; if part of the land is in winter grain this may be followed with cowpeas, soybeans, or lespedeza.

Another difficulty in following definite crop rotations in the Cotton Belt is the fact that on the larger plantations most of the cotton is grown by sharecroppers who have little use for feed crops, and who prefer to grow cotton continuously. Under these conditions there seldom is any attempt made to follow definite rotations, and cotton usually is grown year after year on the same land.

In many parts of the Cotton Belt—particularly in the upland, hilly section—numerous small, irregular fields and a wide variation in the productivity and adaptability of the soil to the various crops grown make conditions unfavorable to the adoption of a definite rotation or sequence of crops that may be applied to the entire farm. On many farms part of the land may be good cotton land but poor cornland; other parts of the farm are good cornland but not well suited for cotton. An attempt to set up and carry out a definite crop rotation for the entire farm under these conditions will necessitate planting cotton some years on land that is low in productivity or otherwise unsuited to its production. Where such conditions prevail it is not an unusual practice to adopt one cropping system for the cotton land and another for the cornland. Cotton well fertilized will be grown continuously on the cotton land, and corn and other miscellaneous crops on the cornland.

As a means of reducing fertilizer expenses and increasing crop yields, considerable interest has been shown in the growing of winter legumes, vetch, Austrian Winter peas, crimson clover, and bur clover, and the acreage planted to these crops has increased tremendously in the Cotton Belt in the past few years. Data from 386 cotton farms on which 4,145 acres of corn and 1,877 acres of cotton were grown after winter legumes showed an average acre increase of 14.1 bushels of corn and 100 pounds of cotton lint where these crops followed a crop of winter legumes plowed under for green manure (*233*). This amounted to an increase of 70 percent in the yield of corn and 35 percent in the yield of cotton. Of the total acreage of winter legumes grown on these 386 farms approximately 58 percent was vetch, 38 percent Austrian Winter peas, and 4 percent crimson clover and bur clover.

While these results were highly satisfactory in the increase of crop yields, only about 6 percent of the cropland on these 386 farms was in winter legumes. This was due in part to the expense of winter-legume seed and in part to the difficulty sometimes encountered in obtaining a stand because of dry weather at seeding time. The most usual practice in seeding winter legumes is to sow the seed in the cotton middles. This is because cotton is cultivated later than corn or other row crops, and the cotton middles usually are relatively clean and free from weeds, whereas corn middles frequently are planted in cowpeas, soybeans, or velvetbeans.

Since cotton is the principal crop, both as regards acreage and value, it is obvious that crop rotations for the Cotton Belt should be centered around this crop. Moreover, the rotation adopted for any particular situation will depend to a large extent on the proportion of cropland that is to be devoted to cotton.

In areas in which approximately one-third of the cropland is in cotton, and where the land is equally well adapted to the production of cotton and corn, a desirable rotation would be:

First year, cotton.

Second year, summer legumes (cowpeas or soybeans) for hay or seed, followed by winter legumes.

Third year, corn, interplanted with cowpeas, soybeans, or velvetbeans.

A variation of this rotation that would be suitable for some sections would be to follow the cotton with a winter grain, which in turn would be followed with a summer legume or lespedeza.

Where it is desirable to have approximately one-half the land in cotton the following rotation is suggested:

First year, cotton, followed in part by a winter legume.

Second year, cotton.

Third year, summer legumes for hay or seed followed by winter legumes.

Fourth year, corn, interplanted with summer legumes.

In this, as in the 3-year rotation, the second-year cotton may be followed wholly or in part by winter grain, etc.

Winter legumes as a green manure may be effectively worked into the cropping system on farms on which the proportion of land adapted to cotton is limited to approximately the required acreage for this crop. Here a limited acreage of winter legumes may be planted on part of the cotton land each year, the plantings being shifted so that the winter legumes will be gradually rotated over the entire cotton acreage. In this way a portion of the cotton will follow a winter-legume crop each year. On the remainder of the farm a rotation of corn interplanted with summer legumes may be grown each year, or the land may be divided into two approximately equal areas and corn alternated with a small-grain crop followed by a summer-hay crop, according to the requirements of the farm.

A rotation of crops is essential in some areas in order to control or hold in check certain cotton diseases. Root rot is the most destructive cotton disease in the United States, and is particularly destructive in the heavy, black, waxy soils of Texas. Root rot also affects practically all farm crops except corn, small grains, sorghums, and grass. It also affects many trees, shrubs, and weeds. Where this disease is prevalent the recommended rotation is cotton 1 year, and corn, small grain, grain sorghum, or a grass crop for 2 to 4 years.

Crop Rotations in the Dairy Region

North of the Corn Belt and east of the wheat region, where the summers are too cool and the growing season too short for maturing corn consistently and where no large tracts of easily tilled, fertile prairie land exist for wheat production, there is a region where hay and pasture predominate. This region includes most of Minnesota, Wisconsin, Michigan, New York, northern Pennsylvania and New Jersey, and the New England States. During the early settlement of this region and up to about 1870 in the Northeast, wheat and corn for grain were grown in considerable amounts. But with the rapid extension of farming in the prairie States, and the development of large and improved machinery, production of corn, wheat, and other small grains increased so rapidly that prices fell too low for the present dairy region to compete in the cash-grain markets. Consequently, adjustments in crops and accompanying adjustments in livestock were started in what is now the principal dairy region of the United States. Practically no wheat and only small quantities of oats and other feed grains are now grown in New England. New York grows slightly more feed grains and also has some wheat production in a limited area of the western part of the State. The Lakes States grow most of the feed grains used by the dairy and work stock on the farms, but they produce little grain for market.

Most of the dairy farms in the Lakes States have some land either too rough for crops or not cleared that furnishes considerable feed for 3 to 6 months when pastured. In this situation a 3-year rotation of corn—mostly for silage—oats, and clover is popular. These States are important potato producers, so that the substitution of some potatoes for corn as the intertilled crop is common. Usually a mixture of clover and timothy or alfalfa and timothy which may be kept 2 years for hay is sown with the spring grain. When permanent pastures are short, the second year of hay may be partly or wholly pastured. If the new seeding fails, the old sod may be kept over another year or an annual hay crop may be sown.

In some cases a field may be kept in alfalfa for 3 or 4 years and then be put in the regular rotation again.

In a representative area in northern Wisconsin a group of farms averaged the following acreages of crops per farm: Corn for silage, 11; corn for grain, 0.5; potatoes, 3; oats, 13; barley, 3.6; and hay, 19. Woods and permanent pasture amounted to 50 acres, and the total farm area to 104 acres. The ratio of cultivated crops to small grains and hay of 14.5, 16.6, and 19 acres, respectively, is due to the fact that a small proportion of the farmers keep their hay seeding down 2 years while most of them keep the hay seeding down only 1 year. It illustrates how a dairy farmer can expand milk production if milk prices increase relative to other products, which is just what has happened on most farms that have remained in dairying in the eastern part of the dairy region.

According to farm-management surveys (*449*, *450*) covering the calendar year 1930, Hunterdon and Sussex Counties in northern New Jersey, although less than 50 miles apart, showed a marked contrast between general farming and highly specialized dairy farming. One hundred and seventy-six farms in Hunterdon County had an average of 69 acres of crops approximately in the proportion of a rotation of corn, oats, wheat, hay, and hay, and also had 29.5 acres of pasture. Ninety-eight Sussex County farms had an average of 64 acres of crops approximately in the proportions of a rotation of corn, oats, hay, hay, and hay and had 91 acres of pasture. By utilizing the tillable land in the dairy area for growing roughage for the cows and the more rolling land for pasture, and supplementing these with liberal rations of purchased concentrates, the size of the dairy business on a given farm can be greatly increased.

In many parts of New York and most of New England the percentage of cropland in hay is even higher than in Sussex County, N. J. In Berkshire County, Mass., hay was the crop harvested on 84 percent of the cropland in 1929. In Grafton County, N. H., hay was on 89 percent of the cropland harvested, corn and oats on 3 percent each, and potatoes on 2 percent. Many hayfields are not reseeded for 10 to 20 years. Under these conditions, hay yields usually decline to a low level.

Crop Rotations in the Wheat Regions

The areas of heaviest concentration of wheat in the United States occur in three regions. In each, a type of wheat adapted to the natural conditions of the area is grown. Definite crop rotations are not a part of farming practice in the important wheat-producing areas. Wheat may not be grown continuously on the same fields, but even those farmers who maintain a higher-than-average proportion of their land in crops other than wheat do not usually follow one crop with another specific crop in orderly sequence. The general disregard for formal crop-rotating systems is not because fertility maintenance or weed control have not become serious, for in certain sections both are important. It is due to climatic hazards that make the continuous-cropping system uncertain; to lack of an easily established legume; and, most important, to the lack of a crop that can compete successfully with wheat in yielding returns for the use of land, labor, and capital.

In general-farming areas extending from eastern Kansas through Missouri, Illinois, Indiana, and Ohio to Pennsylvania, Maryland, and Virginia, wheat has an important, although not a predominant, place in the cropping system. It may occupy no more than one-fifth or even a smaller proportion of the rotated land in a sequence of corn, small grain, and hay or grass. Whatever the sequence of crops, wheat may be grown to obtain a combination with grass seedings or for straw as well as for grain.

The hard winter wheat producing area comprises the western two-thirds of Kansas and extends south into western Oklahoma and northern Texas, west into Colorado, and north into Nebraska. The portions of the area devoted to wheat production may be characterized in general by a level or undulating relief; heavy, fertile soil; and by precipitation decreasing from 25 inches in the eastern portions to 15 or 18 inches in the western portions. Cropping systems vary with precipitation and to some extent with soil type. Crop acreages on a number of wheat farms in Clay and Saline Counties, Kans., as reported by farmers in 1933, when expressed as a percentage of total cropland showed that 62 percent of the 263 crop acres per farm was seeded to winter wheat. Another 6 percent was in oats or barley. Thus, two-thirds of the cropland was in small grains. Corn occupied

18 percent of the land and sorghums for grain or forage 4 percent, which placed a little more than one-fifth of the cropland in intertilled crops. Hay, mostly alfalfa, was reported on 6 percent of the cropland. Farther west, wheat is even more the predominating crop. In the area represented by Russell, Rush, Stafford, and Mitchell Counties, approximately 80 percent of the crop acreage was planted to wheat. Other small grains are relatively unimportant, but in the western portions of the area corn occupied 12 percent and sorghums 8 percent of the land. There was very little hay. In the portions adjacent to the eastern division of the area less corn and more alfalfa were grown.

In the western part of the winter wheat area centering around Ford and Haskell Counties, Kans., and extending to the west, wheat on the grain farms was seeded on 87 percent of the cropland. In the northern portions of the winter wheat region, corn and the small feed grains occupy a larger share of the cropland, and greater opportunities for rotating crops are presented. On the eastern border of the northern limits of the winter wheat area, corn utilizes a larger proportion of the cropland than wheat. Corn is likely to be followed by corn or spring grains and wheat to be followed by spring feed grains or wheat. Roughly the system could approximate a rotation of corn 2 years, oats or barley 1 year, and wheat 2 years with some likelihood that sweetclover or some other hay crop would be included.

Cropping systems common in the spring wheat area, centered in North Dakota and extending into Minnesota on the east, South Dakota on the south, and Montana on the west, are determined by the adaptation of the area to spring-seeded small grain, the limiting influence of temperature and moisture on corn production, difficulties of controlling weed infestations, and to some extent by the effects of plant diseases. In this area as in others in which climate, particularly precipitation, exhibits a high degree of variability, orderly rotations or sequences of crops are not always practicable. Generally speaking, wheat or other small grains occupy the major portion of the cropland. In the southern portions of the area corn is included in the rotation. Potatoes are included on some of the lighter soils in the eastern sections; and sweetclover, used for hay, pasture, or soil improvement, occupies a portion of the land in the eastern Dakotas.

In an area typical of the Red River Valley, one-third of the 440 acres of cropland per farm was either in hard red spring or durum wheat and 27 percent was in other small grains or flax, crops which occupy the same position in the cropping system. Only 4 percent of the land was in a cultivated crop, corn or potatoes, 15 percent was in hay or sweetclover pasture, and 15 percent was either fallow or in crops plowed under for soil improvement. Records on a number of farms included in an earlier study indicated that farmers on lighter soils were approximating a rotation of (1) small grain, 2 years; (2) sweetclover for hay, pasture, or green manure; and (3) corn or potatoes. Other farmers, however, were attempting nothing more than a continuation of small-grain crops with the sequence broken by occasional crops of sweetclover or perhaps row crops. Where the fields were badly weed-infested, farmers might resort to summer fallow to clean their fields.

In the southern portion of the spring wheat area where corn has a definite part in the cropping system, corn occupied about 20 percent, wheat about 40 percent, and small feed grains about 30 percent of the crop area totaling 380 acres. Some alfalfa and a small amount of sweetclover were grown on an acreage equivalent in the eastern part of the area to 6 percent of the cropland. In this area of northeastern South Dakota, 60 percent of the wheat followed spring grains, 10 percent was on fallow, and 30 percent on row-crop land. This distribution of crops would permit a rotation of small grains 4 years and row crops 1 year with a portion of the acreage in legumes.

The cropping systems in the western portions of the spring wheat area are discussed under Dry-Land Rotations.

In the Pacific Northwest—the wheat areas in eastern Oregon, in Washington, and in Idaho—dry-land wheat production has been carried on for nearly 50 years. Beginning with a practice of growing a crop each year, as a means of controlling weeds and to increase the dependability of yields, farmers shifted from continuous wheat, first to a system of fallow every third year, and finally to a system in which the greater portion of the acreage of wheat in areas of 15 to 18 inches of precipitation is now alternated with fallow. In the Palouse section in 1933, 78 percent of the winter wheat and 58 percent of the spring wheat were seeded on fallow, and 23 percent of the winter wheat and 34 percent of the spring wheat

followed cultivated peas. A small acreage of small feed grains was usually seeded after small grains on stubble land.

The typical rotation of the area is more closely followed in the section near Walla Walla, Wash., and in Sherman County, Oreg. In both of these areas and in the Big Bend area of Washington practically all of the cropland is included in a wheat, summer-fallow rotation. The lack of any crop that closely competes with wheat in returns and the practical success of the system has given it wide adoption.

Dry-Land Rotations

There are some points in common between practically all portions of the Great Plains and the intermountain dry-land areas that help determine rotation practices. Wheat, either winter or spring, is the preeminent cash crop, except for a few sections where the soils are unsuitable for wheat production and limited areas where a cash crop of greater value is adapted. The proportion of wheat in the farmer's program, however, varies from almost the sole crop to a place subordinate to feed crops. Sod crops, an integral part of rotation practice in humid and subhumid areas, are unsuitable for short rotations, because of the dry condition in which they leave the soil, and their value in deferred rotations is still to be determined. Manures, both green and stable, are ineffective in increasing grain yields, although they increase the yields of straw and stover. These latter facts explain why dry-land rotations do not conform to some of the general principles considered essential in crop rotations elsewhere.

Summer fallow enters into dry-farming rotations in most sections. The term "summer fallow" as applied in dry-land areas means keeping the land free from weeds or competing crop growth during one crop season in order to store moisture for the next. This differs from the use of the word in other sections where land that stands idle or that grows a crop of weeds part of the year is often termed "fallow."

The place of fallow in rotations depends upon the extent to which it increases crop yields, and on the competition of other crops, particularly cultivated crops. In general, the drier the section and the lower the adaptation of cultivated crops, the more important may be the use of fallow to the agriculture of the section. The use of summer fallow in dry-land rotations is considered in more detail elsewhere in the Yearbook under Special Dry-Farming Problems.

Wind erosion is a factor that must be considered in dry-land rotations. Certain crops, such as annual legumes, leave the soil in condition to blow readily and often are best grown in strips with crops that leave resistant residues. In general, however, the handling of the land and of the crop residues upon it within a rotation are the principal means of controlling wind erosion. Susceptibility to erosion is often the deciding factor in determining the rotation and cropping practices.

Rotation practices involving wheat as a principal crop have been considered under the discussion of crop rotations in the wheat regions. The addition of another crop with an acre value comparable to wheat may profoundly alter farm practice in a section. In portions of Washington, Oregon, and Idaho peas grown in cultivated rows have displaced some of the fallow. The yields of wheat following peas are lower than those following summer fallow, but at prevailing prices the value of the pea crop has been greater than the reduction in value of the following wheat crop.

In the important grain sorghum sections in the southern Great Plains, there is difficulty in suggesting an adequate rotation. Much of the land is too sandy for successful wheat production, and the presence of a high row-crop stubble over winter may be necessary to prevent wind erosion. Growing strips of annual legumes between strips of sorghum in lieu of a rotation has been practiced. The purpose, however, generally has been to avoid destructive soil blowing on legume land rather than to make a conscious effort to rotate crops. On land where winter wheat and sorghums can both be grown and where summer fallowing materially increases the yields of wheat, a rotation of summer fallow, wheat, and grain sorghums may be adapted. By fallowing the sorghum stubble, the severe reduction in wheat yield that is experienced when winter wheat follows sorghum is avoided. A 2-year rotation of sorghum and wheat is not advisable. More sorghum and wheat can be produced by growing each continuously on the same land than by alternating them.

Continuous cropping, either to cultivated crops or to small grains, has not been so bad a practice in the dry-land area as in wetter or irrigated sections.

Manures in dry-land areas must be considered in the light of their potential value in helping maintain the organic-matter content of the soil rather than as a fertility element from which worth-while yield increases may immediately be expected. This value remains to be determined. Cumulative increase of grain yields from rotations containing manures have seldom been evident, even on rotations that have a history of as much as 25 years. Soil studies, however, show that less reduction in organic matter has taken place on rotations receiving manure. Manures have been very useful in improving the physical condition of some heavy soils.

The lack of grass crops or alfalfa in the rotations given does not mean that these crops have no place in dry-land farming. Present knowledge of these crops indicates that they should be planted in favored locations and allowed to stand while production remains good.

Crops other than those mentioned are important in parts of the region. Cotton largely displaces sorghums in the southern part of the Great Plains. Potatoes are an important cash crop in parts of western Nebraska. Dry beans are a cash crop in several States, and dry or canning peas are grown in portions of the intermountain region. Where these cash crops can be successfully grown they assume an important place in the rotations.

In general, it may be stated that the yields of crops and their immediate effect upon each other are the matters of immediate concern in arranging dry-land rotations. Fertility up to the present time has been of secondary importance. The soil was highly productive in its virgin state, and the limitations on production set by the low rainfall characteristic of the region have prevented lack of fertility from assuming an important place as yet. Only continued studies can determine the level of fertility at which it may be the controlling factor in determining the quantity of crop produced.

Crop Rotations in Irrigation Agriculture

The virgin productivity of extensive irrigated areas located in the arid and semiarid West is well recognized, and long-continued investigations have clearly shown that where a satisfactory farm-management program has been in effect, crop yields not only have been sustained, but during a period of over a quarter of a century they have been substantially increased.

At the Huntley (Mont.) Field Station from six untreated rotations for the first 3 years of a long-time experiment, 1912-14, sugar beets returned a mean yield of 10.2 tons per acre, and from potatoes there was a mean yield of 209 bushels per acre from five untreated rotations. These yields are a fair measure of the original productiveness of the soil. After 20 years of continuous and intensive cropping, the mean yield of sugar beets from four constructive rotations including either farm manure or pasturing was 13.4 tons per acre, and from potatoes in four similar rotations the mean yield was 242 bushels per acre. These differences represent an increase of 31 percent for sugar beets and 16 percent for potatoes.

Similar comparisons are available at the Scotts Bluff (Nebr.) Field Station. In its virgin state the land representative of the North Platte reclamation project proved to be somewhat more productive. From six untreated rotations from 1912 to 1914 the mean yield of sugar beets was 16 tons per acre, and of potatoes from five comparable rotations there was harvested a mean yield of 219 bushels per acre. After a lapse of 20 years, from four of the better rotations including sugar beets there was harvested a mean yield of 17.9 tons of beets, and from five rotations including potatoes the mean yield was 252 bushels per acre. These differences represent an increase of 12 percent for sugar beets and 15 percent for potatoes.

There is ample evidence elsewhere throughout the West to demonstrate that where good farming practices are in effect crop yields of a high order are being harvested on such irrigated areas as those lying along the North Platte, South Platte, and Yellowstone Rivers; the Columbia River Basin; the lower Colorado River; and the extensive areas supplied from the waters of the Salt River and Rio Grande. This condition exists even in view of the fact that irrigation farming has been conducted for nearly half a century in a number of these localities.

Extensive acreages, either completely abandoned or unprofitably operated on many irrigation enterprises scattered throughout the West, are impressive demonstrations of the unjustifiable optimism as to the productive future of such areas without a suitable program of management. It has been assumed too generally

that the problems involved in connection with maintaining crop yields were not complex and could be readily solved by the farmers themselves. These all too extensive areas with impaired productivity clearly demonstrate that this is not a fact.

Under proper management and where the soil, water, and climatic conditions are not unfavorable the acre yields of the various crops produced under irrigation should be superior to those harvested where such contitions do not exist. But in eliminating the hazards of drought, which has long been recognized as an important limiting factor in securing large crop yields, and in taking advantage of an assured water supply, farmers assume other responsibilities in connection with their operations, which if not adequately met still endanger their success. A substantial proportion of the costs of crop production under irrigation is in the form of fixed charges, which must be met regardless of the size of the crop harvested or even if there is a total crop failure. Thus, while the possibilities of obtaining larger returns per acre are greater where the hazards of drought have been eliminated, the financial risks are correspondingly increased if the productivity of the soil is not so maintained that superior yields are assured.

Farmers producing crops under such conditions and confronted with increased operating costs are forced into a more intensive system of farming, as mediocre yields will not cover production costs and fixed charges. Such measures as summer fallowing, often resorted to advantageously in adjoining dry-land areas, are not practical. Because of the intensive cropping of the lands, which is essential to success, the productivity of the lands becomes more rapidly depleted unless a soil-improving farm program is practiced, and the ultimate consequences are more serious to the operators than is the case where the required standard of production is materially less. It is evident, therefore, that a successful agriculture under irrigated conditions is predicated upon the adoption of such a program of farm management that crop yields may be large enough to insure returns in excess of the fixed charges and costs incident to their production. To attain this objective a well-planned crop-rotation program is now known to be essential.

The basic purpose of crop-rotation investigations is to provide authentic information as to the crops together with the sequences and the soil amendments necessary to develop conditions favorable for normal, vigorous plant growth. This was the objective when an extensive series of irrigated rotations was inaugurated at the Scotts Bluff, Nebr., the Belle Fourche, S. Dak., and the Huntley, Mont., Field Stations in 1912.

It has been found that the rotation of crops alone is not an insurance against soil exhaustion, even when alfalfa or a similar leguminous crop is included in the cropping program, and that good rotations alone will not maintain crop production indefinitely without supplementary amendments, except in unusual circumstances.

It has been only within the past 5 years that data have been available indicating that yields of sugar beets and possibly certain other crops will eventually decline in rotations with alfalfa to such a degree that the yields are but little better than when grown for a like number of years in simple rotations not including a leguminous crop.

It has taken many years of careful experimentation to provide reliable data as to the merits of varying applications of farm manure as compared with alfalfa and certain other leguminous crops grown in rotations with staple farm crops. Where these crops are grown throughout the irrigated West, farm manure has been found to be the most effective agency in maintaining and improving the productivity of the land. However, this soil amendment is rarely available in sufficient amounts to fulfill the needed requirements. In certain instances mineral fertilizers may be utilized to advantage, but their cost is an important item, particularly when the prices of farm products are depressed. Often, therefore, it is necessary for the farmer to provide other means of maintaining the productivity of the soil. In such instances a promising solution of the problem is the inclusion in the rotation of such leguminous crops as alfalfa or sweetclover, and pasturing one season during the cycle of the rotation. It has been found that by pasturing alfalfa or sweetclover production costs are reduced, the net returns per acre are greater than those obtained when the hay is marketed, and subsequent crop yields are stimulated to an extent often equaling such intensive treatments as the inclusion of alfalfa and applications of farm manure when combined in the same rotation.

Crop Yields Materially Influenced by Crop Sequences

It has been found that where three or more crops are grown in rotation the arrangement of the crop sequences often has an important effect on the yields of certain of the crops. Investigations have shown that where sugar beets are grown in a 3-year rotation with oats and potatoes, the yields of sugar beets are definitely depressed if oats are the preceding crop but are satisfactory following potatoes. On the other hand, potato yields have been satisfactorily maintained following oats. Thus if oats or similar cereals are included in the farm program which also includes potatoes and sugar beets—crops commonly grown on a number of the larger projects—the proper arrangement of the crop sequences is highly important. Leguminous crops such as alfalfa and sweetclover, which are so extensively included in the farm program for soil-improvement purposes, are commonly grown 2 or more years, after which the land is prepared for the more important revenue-producing crops. Cropping programs including sugar beets, potatoes and 2 or more years of alfalfa are characteristic of the practices found on many irrigation projects. Ordinarily the yields of sugar beets immediately following alfalfa are low, but relatively satisfactory yields are to be expected from potatoes immediately following alfalfa. Sugar beets following potatoes in such a rotation have shown increases of more than 70 percent in excess of the alfalfa, sugar beet, and potato combination, and at the same time the yields of potatoes following alfalfa have compared favorably with rotations in which the crop is one or more years removed from alfalfa. Often such results as these have confused farmers and at times have led them to question the benefits to be derived from including alfalfa in the planting program. It is fortunate that now more precise information is available as to the probable effect on crop yields of various crop sequences.

COVER CROPS *protect the soil in various ways; green-manure crops add organic matter, affect the supply of plant nutrients, and improve the physical condition of the soil, which is important in erosion control. Both legumes and nonlegumes may be used for these purposes, but each has distinct functions and results. In addition to discussing these questions, this article pays special attention to the use of cover and green-manure crops in the South, listing those that are recommended and others that are still in the experimental stage.*

The Use of Cover and Green-Manure Crops

By A. J. Pieters *and* Roland McKee [1]

A GREEN-MANURE CROP is one used for turning into the soil, whether planted for that purpose or not, and irrespective of whether the crop is turned under while still green or after maturity. A cover crop is one used to cover the soil surface without reference to incorporation with it.[2] The function of a cover crop is mechanical, as to prevent erosion and leaching, to shade the ground, or to protect the ground from excessive freezing and heaving. This is often of special importance in orchards and elsewhere. The function of a green-manure crop is to add organic matter to the soil. As an incident to this function the nitrogen supply of the soil may be increased and certain minerals made more readily available, these effects in turn increasing the productivity of the soil.

WHY CROPS ARE TURNED UNDER

The practice of green manuring is very ancient, while the use of cover crops as such is of relatively recent origin. The Greeks turned under broadbeans (*Vicia faba* L.) 300 years before the time of Christ, and the planting of lupines and beans (*Phaseolus* spp.) for soil improvement was a common practice in the early years of the Roman Republic. The Chinese wrote about the fertilizing value of grass and weeds several hundred years before our era. Buckwheat, oats, and rye were used in this way by the American colonists before the middle of the eighteenth century, and toward the end of that century Mary-

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[2] Whole the terms "cover crop" and "green-manure crop" are not identical, recent practice has made them stand for practically the same thing. Strictly, a cover crop is one used to cover and protect the ground, more especially during winter. In this sense a grain crop serves as a cover crop in winter and a broadcast cowpea crop is an efficient summer cover crop. Usually, however, the term "cover crop" is not applied to a grain crop intended for grain, nor to a cowpea crop planted for hay, but to crops planted for cover and soil-improvement purposes.

land and Virginia farmers used the partridge-pea (*Chamaecrista fasciculata* (Michx.) Greene) for soil improvement. The extensive use of cover and green-manure crops in the United States is a more recent development and has coincided with the realization that land too long cultivated loses its productive power. Since the soils of the Atlantic seaboard and Southern States have been longest in cultivation and most persistently cropped, it is natural that the most important data on the value of green manuring accumulated in the United States should come from the experiment stations of this region.

Green-manure crops are used in the expectation that the yields of subsequent crops will be increased, and this hope is commonly realized. Inquiry might well be made as to why the turning under of crops has this effect. The answer is that the addition of plant material increases the content of organic matter in the soil. This results in physical improvement of the soil and stimulates all those biological and chemical processes which in the aggregate result in an increase in soil productivity. When legumes are turned under there is in addition an increase in the nitrogen content of the soil.

Importance of Organic Matter in Soil[3]

The soil is not only an aggregation of fragments derived from decomposed rock; it is a mixture of these and organic matter. In the United States soils best supplied with organic matter are in general the ones on which the largest crops are produced, and as a soil becomes depleted of organic matter its ability to produce good crops declines.

Decayed plant material is the source of nearly all of the organic matter in the soil. The roots of plants have undoubtedly been the greatest source of organic matter, and roots of farm crops add appreciably to the amount in soils. This is supplemented by stable manure and by green manures turned under (fig. 1). The amount of organic matter that may accumulate through decay of roots or the addition of green manures will vary with conditions, but comprehensive data on this point are very meager. Obviously, not all the plant material turned under becomes part of the soil humus. A large part disappears during decay as carbon dioxide. Under some conditions, as on sandy soil in a hot climate, this loss may be so excessive that no permanent addition to the soil organic matter is made even by turning under a heavy green-manure crop.

No very large addition to the soil organic matter can be expected from turning under a single green-manure crop. If a crop of vetch that will yield a ton of dry matter per acre is turned under, about one-half will be quickly lost as carbon dioxide or in other ways, and the balance, or about 1,000 pounds per acre, will become for a limited time a part of the humus. If a soil contains 2 percent of organic matter in the surface soil, the organic matter will weigh approximately 40,000 pounds per acre. By adding 1,000 pounds a year, 40 years would be required to double the organic matter in this surface soil, if it were all permanently retained. This illustration, while a rough one, is introduced to point out that in the main the object of green manuring must

[3] For more complete discussion of organic matter in soils see Soil Organic Matter and Soil Humus, p. 929, and Loss of Soil Organic Matter and Its Restoration, p. 347.

be to maintain rather than to increase the quantity of organic matter in soils.

The New Jersey Agricultural Experiment Station (*279*)[4] concluded that turning under green-manure crops retarded the loss of soil organic matter but did not increase the amount, while grass sod, down for 2 years, increased the humus content by 1,340 pounds per acre.

A soil in sod is being slowly enriched in organic matter. Loss begins with cultivation, when decay of the sod and roots sets in, nitrogen and minerals are set free for the use of the cultivated crop, and by a process of oxidation the carbon dioxide is released and organic matter lost. The longer cultivation is continued, the more the soil is depleted of organic matter.

This loss of organic matter is not to be altogether deplored, as the decrease is in large part merely the necessary accompaniment of making the soil organic matter available to crop plants. The fact must be

FIGURE 1.— Turning under a heavy vegetative growth to add organic matter to the soil.

recognized, however, that cultivation is necessarily accompanied by a loss of organic matter, and that if this is allowed to go too far declining crop yields will result. The use of farm land should be so planned as to maintain the organic matter so far as is consistent with a reasonable use of the soil.

LEGUMES AND NONLEGUMES AS COVER CROPS

Both legumes and nonlegumes are used as cover and green-manure crops. The chief difference between them is that legumes add both organic matter and nitrogen to the soil, whereas nonlegumes add organic matter only.

From the standpoint of maintaining the organic matter of the soil,

[4] Italic numbers in parentheses refer to Literature Cited, p. 1181.

bulk is of first importance, and this can often be supplied more efficiently by such a crop as rye, sorghum, or mustard than by a legume. A crop of a nonlegume supplies a large amount of energy material, but it must not be forgotten that the bacteria responsible for the decay of this material must have access to nitrogen. If the nitrogen carried in the green-manure crop is not sufficient, the bacteria will draw on the available soil nitrogen and may deplete it to such an extent as to ruin the following crop. It is not uncommon to find that turning under a nearly ripe crop of rye has been a detriment to the next crop. A legume crop, on the other hand, carries with it more than enough nitrogen for its decay, and this excess becomes available to the following crop.

HOW MUCH NITROGEN IS ADDED TO THE SOIL BY LEGUMES?

The amount of nitrogen added to the soil by legumes depends on the kind of legume, the condition of the stand, and the stage of growth at which the legume is turned under. No general estimate can be given. Some data are available and may be cited as illustrations of possibilities, though they are probably rarely applicable to specific conditions.

The amount of nitrogen in a legume when turned under represents the nitrogen it has taken from both the soil and the air, but the amount taken from the air is all that is really added to the soil. The relative amounts derived from each of these sources are difficult to determine, and it can only be stated that as a broad average about two-thirds of the nitrogen in a legume is believed to have been taken from the air and one-third from the soil.

Duggar (*93*) found that the acre weight of air-dry vines, roots, and stubble of hairy vetch cut April 19 was 3,967 pounds, containing 137 pounds of nitrogen, while that cut May 9 weighed 6,870 pounds and contained 202.8 pounds of nitrogen. Penny (*297*) found that the amount of nitrogen in crimson clover varied from 139.8 to 188.2 pounds, and Willard (*467*) showed that sweetclover turned under the first week in April contained 124 pounds, while that turned under the last week in May contained 160 pounds. The figures for the three crops mentioned are all of the same general order of magnitude and show that the amounts of nitrogen added in these cases would have been equal to the application of 600 to 800 pounds of nitrate of soda per acre.

UTILIZATION OF GREEN MANURES

The amounts of organic matter, and, in the case of legumes, nitrogen, are not the sole factors determining the crop to be used for green manuring or the time to turn it under.

Cover and green-manure crops should be used when they least interfere with the regular cash crops. In the South, winter cover crops fit into the farm program most effectively. In the North, catch crops following grain crops or planted with them can often be used to advantage. In trucking areas, catch crops frequently can be utilized, and legume crops in the regular rotation serve in effect as green manure. It is generally considered that giving over the entire crop season

exclusively to a green-manure crop is seldom profitable, but it is perhaps justifiable when the succeeding crop is more or less permanent and the establishment and good growth of the seedlings or young plants are of prime importance. Preceding permanent orchard plantings, a full year or more given over to green-manure crops might be justified, and where fall seeding of lawns is practiced a summer green-manure crop of soybeans, cowpeas, or some other legume can well be used to prepare the land for the grass seeding.

In the South, when a legume is plowed down in early fall it should be followed with rye or some other winter-growing crop to prevent leaching of the plant food released in the decaying of the turned-under crop and to stop erosion. If it is not to be followed by such a winter crop, the summer green manure should not be plowed under green but should be cut or disked in the fall and allowed to remain on the surface as a mulch or lightly worked into the soil so as to delay decay and prevent loss during the winter months by both leaching and erosion.

In northern latitudes there is relatively little leaching during the winter period, and it is seldom profitable to grow a crop merely to prevent this small loss. A regular winter small-grain or similar crop, however, will greatly reduce loss by erosion.

In the case of abandoned or worn-out lands a cover crop should be sown to occupy the land more or less permanently, using a legume when possible. In certain parts of the South annual lespedeza and crotalaria can be used in this way. Sometimes a green-manure crop can be planted in late spring or midsummer following an early cash crop such as wheat, oats, or some truck crop. Whether a crop thus grown can best be used exclusively for green manure or in part for forage and in part for green manure will have to be determined by the probable cash value of the succeeding crops and the value of the forage that might be obtained. In this connection it should be mentioned that the use of a legume in rotation as one of the regular cash crops is a very economical way of maintaining soil fertility and crop production. The roots and stubble of the legume return to the soil considerable organic matter high in nitrogen at practically no cost.

It should be made clear to every user of green-manure crops that when large quantities of green organic matter are turned under or otherwise incorporated with the soil, some time must be allowed to elapse before planting a succeeding crop, in order to avoid injury, by decomposition products, to the seedlings of the crop to be planted. In the South, a green-manure crop should be turned under about 2 weeks before planting corn and 3 weeks before planting cotton.

When cover crops are planted in orchards the season of growth of the trees and the time and manner of incorporating the crop into the soil become matters of importance. It is necessary with an annual crop to plant at such time as to interfere as little as possible with tree growth and fruit development, but some attention must be given to the harvesting operations. The incorporating of any crop with the soil should be done if possible when the tree roots are not in active growth, and if this is not possible the green manure should be lightly worked into the soil or left on the surface as mulch. The best method for one section and for a given crop will not be the same for all sections

and all crops, but the important fact to remember is that the decay of the green-manure or cover crop should occur at the time when it will best serve as fertilizer for the crop it is to benefit (fig. 2).

EFFECT OF TURNING UNDER GREEN MANURES ON YIELD OF SUBSEQUENT CROPS

Legumes

Experimental work on the effect of green-manure crops on the yield of subsequent crops has been done by many of the State agricultural experiment stations. The work of nine Southern States has been

FIGURE 2.—A cover crop of crimson clover planted in a pecan orchard to add organic matter to the soil and prevent erosion.

brought together by the Agricultural Adjustment Administration (*424*, *425*). The increased yields reported as a result of turning under winter legume crops have ranged from about 6 to 60 percent over the yields of the check plots (fig. 3). An average would not give a true picture of the facts, since the conditions varied so widely. In two cases increases as low as 1.25 and 1.89 percent were recorded, but these results were probably due to some unfavorable condition not reported.

In Alabama increased yields of cotton after cowpeas and vetch were cumulative, being greater in the second 10-year period than in the first and rising in the third period to 116.62 percent on the vetch area and

198.28 percent on the cowpea-vetch area over the yield from continuous cotton.

In Georgia and in Louisiana increases in cotton yields following the turning under of legumes ranged in round numbers from 22 to 100 percent in various experiments.

Similar increases have been shown in the case of corn, the turning under of a winter legume having usually increased the corn yields in experiments in Georgia, Mississippi, South Carolina, and Virginia from 24 to 78 percent. In the Corn Belt, too, where sweetclover is extensively used as a green-manure crop, increases in corn yields are the rule. Crosby and Kephart (*79*) studied the records of a number of

FIGURE 3.—The corn on the left was grown without a cover crop. That on the right followed a winter cover crop of hairy vetch.

farms and found that on poor to medium soils the turning under of a crop of sweetclover increased corn yields by 64 percent, and on soil in good tilth by 36 percent.

In Virginia the regular turning under of crimson clover that had been seeded in the corn at the time of last cultivation improved the land in 5 years so much that the corn yield increased from 15 to 18 bushels once in 3 years to 50 bushels per acre every year.

The turning under of summer legumes has also served to increase yields. In Alabama corn following velvetbeans turned under, without the addition of phosphate, yielded 58 percent more than without velvetbeans but with phosphate. When 100 pounds of superphosphate per acre was also applied to the corn following velvetbeans the increase

was 90.72 percent. Even velvetbean stubble alone increased the yield by 32 percent. In Arkansas the turning under of a crop of cowpeas increased corn yields 62 percent, soybeans 56.6 percent, and velvetbeans 27 percent. When these legumes were cut for hay and only the stubble was turned under, the increases were approximately 30, 14, and 24 percent. When oats were grown and a catch crop of cowpeas following the oats was turned under, the increase in the oat crop was 46 percent, and when a catch crop of soybeans was turned under the increase was 21 percent.

In Louisiana soybeans turned under increased corn yields 106.7 percent, and even when the soybeans were cut for hay the increase was 56 percent.

In Tennessee the yield of corn after sweetclover was increased 52 to 151 percent, and corn yields following lespedeza increased 27 to 132 percent in Tennessee and 74 to 310 percent in various trials in North Carolina.

Red clover is not commonly used solely as a green-manure crop, but the turning under of the second growth is a common practice and one that is richly rewarded.

In Canada fodder corn following a catch crop of red clover in wheat, oats, or barley showed materially increased yields over those on plots on which no catch crop of clover was grown.

In Wisconsin potatoes grown after red clover was turned under without fertilizer produced more than 234 bushels per acre, compared with about 183 bushels on heavily manured or fertilized land and about 168 bushels on the check plot.

At the Iowa Agricultural Experiment Station the turning under of sweetclover produced a 17-percent increase in corn and an 18-percent increase in oats. In Illinois corn following sweetclover turned under yielded 35, 37, and 52 percent, respectively, more than corn on adjoining plots without sweetclover. There are also records of heavy increases in the yield of beets from turning under sweetclover.

The entire record consistently indicates that the turning under of a legume crop increases yields.

Nonlegumes

While a nonlegume will add organic matter to the soil, the soil microorganisms, as previously explained, require nitrogen to effect decay. The turning under of rye or other grain has commonly resulted in a decrease in the following corn or cotton crop because of exhaustion of the soil nitrogen. However, the data available do not always show the age of the green-manure crop when it was turned under, and it has been shown that this factor has an important influence.

At Tifton, Ga., rye turned under March 1 increased by 39 percent the yield of the following cotton crop when the latter was grown without nitrogen, while in the same experiment the increase following Austrian Winter peas (a legume) was 76 percent. When nitrogen was used on the cotton the increased yields were 29 and 32 percent, respectively, for rye and Austrian Winter peas. In the same experiment rye turned under March 15 depressed the yield of corn grown with nitrogen by 1.34 percent and without nitrogen by 6.3 percent. In a Louisiana experiment oats and rye turned under March 20 depressed cotton

yields by 11.82 and 7.68 percent, respectively. In another Louisiana experiment rye depressed cotton yields by 15.5 percent, and compared with cotton that received 150 pounds per acre of nitrate of soda the reduction in yield was more than 40 percent.

In another Louisiana experiment rye and oats turned under about April 10 depressed corn yields on limed land by 4 and 32 percent, respectively, and on unlimed land by 3.36 and 4 percent.

In Virginia corn yields were depressed 21.5 percent by rye turned under when in head and 15 percent when the rye was cut for hay and the stubble was turned under.

It is evident that grain cover crops must be turned under young or adequate supplies of nitrogen must be added to the soil to facilitate decay. Young rye contains a higher percentage of nitrogen and a lower percentage of fiber than old rye.

RESIDUAL EFFECT OF A GREEN-MANURE CROP

When a crop such as clover, vetch, or cowpeas that could have been cut for hay is turned under, the increase in the following crop may or may not be great enough to pay for the hay lost. In comparing the returns, however, it should be taken into consideration that the green manure may have a marked effect on yields of subsequent crops for 2 or more years. At the Alabama Agricultural Experiment Station at Auburn, corn the second year after velvetbeans outyielded that without green manure by 40 percent, and in the third year the effect of the green manure was still evident. At the Canebrake branch station in the same State the effect of turning under bur-clover and crimson clover was evident in increased cotton yields over a period of 3 years.

At the Louisiana Station at Baton Rouge, the residual effect of a number of winter green-manure crops was apparent in increased yields for 2 years, while at the substations at St. Joseph and Calhoun increased yields were noted for 3 years. The Calhoun substation has also reported an increase in the yield of cotton in the third year owing to residual effects of soybeans planted with corn, and the Delta branch station at Stoneville, Miss., has reported similar results in the second year.

The Oklahoma Agricultural Experiment Station reports an increased yield of wheat for 3 years following a green-manure crop of Austrian Winter field peas, while at the Kansas Station alfalfa cropped for a period of 2 years produced a favorable residual effect on succeeding wheat crops over a period of at least 8 years.

The Rothamsted Experiment Station, in England, reports that the residual effect of cultivated legumes was apparent in the yields of cereals for several years after the legumes had ceased to be grown, and the Central Experimental Farms, Ottawa, Canada, have reported increased yields of corn, oats, and potatoes in the second, third, and fourth years, respectively, owing to the residual effect of a previously grown red clover crop.

This residual effect may be due in part to the improved mechanical condition of the soil and the gradual release of nitrogen as decay of the organic matter progresses, but other factors not yet understood are no doubt involved.

EXTENT TO WHICH COVER AND GREEN-MANURE CROPS ARE USED

The use of cover crops seeded especially for turning under as green manure is most general in the Atlantic and Gulf States, but even there vast areas are left bare on which soil productivity could be increased and soil erosion lessened by proper use of available legumes.

In 12 Southern States, out of more than 119.5 million acres of cropland, only 1.73 million were seeded to winter cover crops,[5] while nearly 18.5 million acres were lying fallow (*428*).

It is impossible to say how many acres of cowpeas, soybeans, velvetbeans, or other legumes were turned under for soil improvement, but if half of all the legume acreage recorded, including that planted to peanuts, be added to the winter cover-crop acreage as being useful in some way for soil improvement, the total is still less than half the acreage lying fallow in these States. There is room for vast improvement in conditions through wider use of cover and green-manure crops.

On the sandy lands of the potato section of New Jersey, cover cropping is generally practiced, and it is of interest to note that here the physical effect of the organic matter is of most importance. For nitrogen, reliance is placed on artificial fertilizers. Rye, the cover crop most used, is turned under when it is only a few inches high. In the potato section of northern Maine, red clover and crimson clover are largely used. In the Corn Belt, sweetclover is the standard green-manure crop, the object being to supply the corn with plenty of nitrogen throughout the growing season. No accurate data, however, are available on the extent of this practice. It has been estimated that in Indiana some 50,000 acres of sweetclover are turned under annually for green manure preceding corn crops, and in Ohio probably 30,000 acres. In Illinois it seems probable that 45 to 50 percent of the acreage seeded to sweetclover is used for green manure, and since there are about 800,000 acres of sweetclover in that State, an estimate of 300,000 to 400,000 acres used for soil improvement may be reasonable.

In the Southern States the crops most commonly used for winter cover and green manure are Austrian Winter peas and hairy vetch. Only estimated figures of the acreage planted are available. It ranges from 100,000 to 400,000 acres for the various States.

Cover cropping is a common practice in orchards from New York to Iowa and also on the Pacific coast. In the apple orchards of Washington and Oregon cover crops are almost universally used, and this is a standard practice in the citrus groves of southern California and to a less extent in the Santa Clara and Sacramento Valleys.

PRINCIPAL COVER AND GREEN-MANURE CROPS

The most important cover crops as determined by current use are hairy vetch, Austrian Winter peas, rye, crimson clover, crotalaria, sweetclover, and alfalfa. Other crops of lesser importance are used in limited areas or in much less acreage in accordance with the availability of seed at low cost or by reason of some special crop require-

[5] The cover-crop acreage is an estimate made up largely from figures supplied by State agronomists. In the Agricultural Adjustment Administration's report for 1936 the area seeded to green-manure crops in these States is given as 4,605,600 acres.

ment (fig. 4). Crops recommended for use and those being used in experimental work in the Southern States are given in table 1.

Hairy vetch as sold commercially represents two distinct forms or varieties. One of these is distinctly hairy or pubescent, while the other appears to be almost smooth. The former in general is the more winter-hardy but will not make growth at as low a temperature as will the smooth form. For this reason the smooth variety is to be preferred for planting in the South as a winter cover crop. The hairy form is to be preferred for planting in the more northern latitudes because of its winter-hardiness.

The Austrian Winter is the most winter-hardy of the field pea varieties. It has a low minimum-temperature growing point and in

FIGURE 4.—*Lespedeza sericea* in rows with volunteer plants making a complete ground cover.

this respect is superior to hairy vetch. Under southern winter conditions it makes good growth and is one of the best legumes for general use.

While rye is not a legume, it is one of the best cover crops for extreme situations where fertility is low and winter temperatures are apt to be extreme. It will make growth at lower temperatures than will any of the legumes and often will afford a cover when other crops give but little protection. Attention should be given to adapted varieties if best results are to be obtained.

Crimson clover makes an excellent winter cover crop for the northern part of the Cotton Belt and is one of the few winter legumes of which

Table 1.—*Soil-improving crops recommended and being used in experimental work in the South, as reported by various State experiment stations*[1]

Crop	Alabama	Arkansas	Florida	Georgia	Louisiana	Mississippi	North Carolina	Oklahoma	South Carolina	Tennessee	Texas	Virginia
Alfalfa		E								R		R, E
Beggarweed		E	R	E	E						E	
Bur-clover	E	R, E			R, E	R		R		R	E	E
Black medic		E		E	E			R		R	E	
Cassia tora				E								
Clover:												
Alsike					E			R, E		R	E	
Crimson	R, E	R, E		R, E	E	R, E	R, E	R, E	R	R	E	R, E
Hop					E			R, E		R		R, E
Cluster					E							
Persian					E							
Red		E			E			E		R	E	R
Subterranean					E							
White					E			E		R	E	
Cowpeas	R, E	R, E	R	R	E	R, E	R, E	R, E	R, E	R	R, E	R, E
Crotalaria:												
grantiana					E							
incana					E		R, E					
intermedia		E	E	E	E				E	E	E	
lanceolata					E							
maxillaris					E							
spectabilis	R, E	R, E	R, E	R, E	E	R, E		R, E	R	E	E	E
striata		E	R, E	E	E	E			R	E	E	
usaramoensis					E							
Field peas, Austrian Winter	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R	R, E	E
Glottidium vesicarium				E								
Kudzu	R, E	E		R, E		R, E	R			R		
Lespedeza:												
sericea	E			E		E	E	E		R	E	E
stipulacea	E			R			R	R		R	E	R
striata	R			R		E	R	R		R	E	R
Lupine:												
Blue			E	E								
White			E	E								
Mung bean		R, E						R, E		R	E	
Oats		E	R, E	R, E	E		R, E	R, E			E	
Peanuts	E	E		R, E					R			
Rye	E	R, E	R	R, E	E	E	R, E	R, E	R, E			R, E
Ryegrass					E			R, E			E	R, E
Serradella				E								
Sesbania		E	R, E		E	E					E	
Snap beans							E					
Sour clover					R, E						E	
Soybeans	R, E	R, E		R	R, E	R, E	R, E	R, E	R, E	R	E	R, E
Sudan grass		E					R, E	R, E				
Sweetclover		E						R, E		R	R, E	R, E
Sweetpotatoes							R, E					
Tangier peas			E	E	E						E	
Tepary beans								R, E				
Velvetbeans	R, E	R, E	R	R, E	E	E	R, E	R, E	R	R	E	
Vetch.												
Common	E			E	R, E						E	
Hairy	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R, E	R	R, E	R, E
Hungarian	E	E		E	R, E			R, E				
Monantha	E			E	E							
Purple					E							
Woollypod				E	E	E						
Weeds			R, E				R, E		R, E	E		

[1] R=recommended; E=being used in experimental work.

seed can be produced satisfactorily in this region. Unfortunately, however, stands of crimson clover are somewhat difficult to obtain, and for this reason its use has been greatly limited. The seed germinates easily, but when once sprouted it is very readily injured by subsequent drying. For this reason seed that is germinated by a light

rain may subsequently be killed by the dry weather that usually prevails at fall seeding time. Attention to seedbed preparation and moisture conditions at time of seeding and the use of seed in the chaff will help greatly in overcoming this difficulty.

Crotalaria, although a recent introduction, has already become of importance as a soil-improving crop in the South. It is especially suited to sandy soil and is much better adapted to soil of low fertility than most other crops. The fact that seed can be produced locally wherever it is adapted makes it especially serviceable in the Cotton Belt, since seed cost is an item of importance. Crotalaria produces a high percentage of seed which, though hard, can be scarified satisfactorily and the small size and good yields of which assure a low cost.

Alfalfa is used exclusively for a cover and green-manure crop in very limited areas, although in rotations it is recognized as one of the most important soil-improving crops. Its deep-penetrating root system opens up heavy soils and together with the large top growth adds large quantities of organic matter. Being a long-lived perennial, it makes an effective permanent cover crop and is recommended for orchards or other permanent plantings in regions where it succeeds.

Sweetclover, like alfalfa, has a deep taproot and produces a large tonnage of organic matter. Being a biennial, it cannot be used as a permanent planting but only in rotations. It is perhaps the most satisfactory legume for use in the Corn Belt for cover crop and green manure, as it fits in well with a corn-wheat rotation. Both alfalfa and sweetclover can be successfully grown only where the soil is well supplied with lime and phosphates.

Other crops, such as red clover in the North and lespedeza in the South, while rarely used exclusively for green manuring, have a distinct place in a soil conservation program. Used regularly in a rotation, they tend to prevent soil loss and decline in soil productivity. The best crop to use in a given district must be determined finally by local conditions and objectives, but it will most likely be one of those in common use and of known adaptation.

EFFECT OF COVER CROPS IN CONTROL OF SOIL EROSION

Cover crops tend to prevent soil erosion in two ways. While the crop is growing the plant canopy acts to protect the soil from the impact of rain and to retard the run-off. The turning under of the cover crop as green manure adds to the organic matter of the soil and increases its permeability, thus enabling the water to soak in more rapidly, with a resultant decrease in run-off and erosion.

The effect of the cover in decreasing erosion has been shown in many experiments by the Soil Conservation Service, the results of which are more fully presented elsewhere in this Yearbook (Grass and Other Thick-Growing Vegetation in Erosion Control, p. 615).

At Statesville, N. C., on the soil-erosion experiment field, the record for 1931–35 (table 2) shows that a cover of lespedeza almost wholly prevented erosion.

The loss by erosion from the lespedeza plot was less in later than in earlier years, owing to the increasing denseness of the stand.

These figures suggest that many thousands of acres in the South now lying idle and subject to erosion could profitably be seeded to lespedeza

Table 2.—*Average annual soil loss and run-off at Statesville, N. C., 1931–35* [1]

Plot	Soil lost	Run-off	Plot	Soil lost	Run-off
	Tons	*Percent*		*Tons*	*Percent*
Fallow	64.56	29.60	Cotton	13.87	8.79
Corn	20.19	9.21	Lespedeza	.63	5.61

[1] Data supplied by Soil Conservation Service.

even if an initial application of phosphate be needed to insure a stand.

The turning under of a green-manure crop increases the content of organic matter, and in soil conservation work at Clarinda, Iowa, this has been shown to affect the rate of erosion (*275*). Between 1932 and 1935 a plot in corn without stable or green manure lost 77.41 tons of soil, while a corresponding plot on which tall sweetclover had been turned under lost only 12.53 tons. The authors reporting that work add (*275, p. 56*): "The addition of organic matter in the form of green manure, stable manure, etc., considerably increases the infiltration rate."

At Temple, Tex., a green-manure crop of vetch introduced into a rotation of corn, oats, and cotton reduced erosion to less than half that from a plot similarly treated but without a winter cover and green-manure crop.[5]

[5] From unpublished data of the Soil Conservation Service.

MANURE to the amount of a billion tons a year is produced on American farms. Theoretically it is capable of producing $3,000,000,000 worth of increase in crops, but only a small part of its value is actually realized. Much of the loss is due to faulty handling. This article gives a thorough practical discussion of the whole problem of handling manure for maximum effectiveness with a realistic regard for American conditions.

Farm Manure

By Robert M. Salter *and* C. J. Schollenberger [1]

ONE BILLION TONS of manure, the annual product of livestock on American farms, is capable of producing $3,000,000,000 worth of increase in crops. The potential value of this agricultural resource is three times that of the Nation's wheat crop and equivalent to $440 for each of the country's 6,800,000 farm operators. The crop nutrients it contains would cost more than six times as much as was expended for commercial fertilizers in 1936. Its organic matter content is double the amount of soil humus annually destroyed in growing the Nation's grain and cotton crops.

Unfortunately, only a small fraction of the potential crop-producing and soil-conserving value of manure is actually realized. Probably one-half of the excrements from farm stock is dropped on pastures and uncultivated ground. From the part handled as manure, there are enormous losses through failure to save the valuable liquid portion, through loss of nitrogen in improper fermentation and drying, and through leaching of the remaining available nutrients from storage piles exposed to heavy rainfall. Even after it is spread upon the field, serious losses from volatilization of ammonia are probable if fermented manure dries before it is effectively incorporated into the soil, or at least before the soluble constituents have been leached out and absorbed by the soil. As a final factor in the inefficient use of manure, it is not always applied at the season, in the manner, at the rate, or to the crop which would give the greatest return. Considering these facts, it is probably safe to assume that only a quarter or a third of the potential value of the manure resource of the country is now realized.

The economic possibility of preventing much of this loss has been conclusively demonstrated, both experimentally and practically.

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The wasteful and inefficient methods of handling manure seen in all sections are evidence that many farmers still do not understand the true nature of manure, the perishable character of its most valuable constituents, and the direct money loss incurred through its improper treatment. A study of the facts regarding the production, losses, care, and field management of manure should help any farmer better to understand the problem and work out a solution practical for the conditions of his own farm.

Results obtained at a number of American experiment stations indicate that at present crop prices the average value of manure as fertilizer is about $2.50 per ton. This figure will vary with soil and crop—the range of estimates is from $0.96 to $4.11 for general crops in Indiana and about the same in Iowa. The average for 36 tests in Maryland was $5.28, and for truck crops only, $8.67. Assuming an average value of $2.50 and that two-thirds of the potential manure production from feeding all crops except wheat grain is recovered, the annual value of the manure from 100 acres of land producing 50 bushels of corn, 40 bushels of oats, 25 bushels of wheat, and 2 tons of hay per acre in rotation would be $500. By better handling and the use of fertilizer supplements this value might be materially increased.

The greatest benefits from manure are only to be realized from intelligent use in combination with other practices that constitute good soil management—proper crop rotation, lime if needed, supplemental fertilization, adequate drainage, high-quality seed, and good tillage practices. Data from long-time field experiments in which manure has been used to good advantage are presented in table 1. The soils are typical of the regions, but crop yields are nearly double the average. In both these experiments, the amount of manure applied was about two-thirds the potential production, which is not beyond possibility on any well-managed livestock farm.

THREEFOLD VALUE OF MANURE

Farm manure is the mixture of animal excrements with soiled bedding, etc., which accumulates in stables. Its value for maintaining and improving the productivity of the soil has been recognized from the earliest times. Manure is of value in soil improvement because of its content of fertilizer materials, of humus, and of certain organic constituents. These will be considered separately.

In comparison with commercial fertilizers, average farm manure does not rate high. The formula in the usual fertilizer parlance may not be much above 0.5–0.25–0.5, meaning percentage of nitrogen, phosphoric acid, and potash, respectively. Of the nitrogen, two-thirds or more is in slow-acting forms. Commercial fertilizer equivalent to 1 ton of average manure can be purchased for $1.25 to $2 at the present time, and the expense of applying 100 pounds of 10–5–10 fertilizer is much less than that of applying a ton of manure. On soils in good condition, the returns from the fertilizer will usually be greater. For these reasons many authorities minimize the value of manure as fertilizer.

It is more generally agreed that the chief benefits from manure are indirect. By supplying humus, it improves the tilth or physical character of the soil as well as the water-holding capacity, aeration,

and temperature relations, and it has a favorable effect on the biological activities of lower organisms that work over the stock of plant nutrients in the soil and make them available for immediate use. The physical properties of soils both too heavy and too light are generally considered to be improved by an increase in the humus content, which undoubtedly can be effected to a certain extent by manuring.

Table 1.—*Results from complete fertility systems including manure*

Location, soil type, and experiment	Treatment	Average crop yield: Corn	Oats	Soybeans	Wheat	Hay	Average annual value of crops [1]	Annual cash cost [2]	Annual net value
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Tons*	*Dol.*	*Dol.*	*Dol.*
Wooster, Ohio; Wooster silt loam; 31 years' data from 45-acre variety ranges. [3]	Corn: 10 tons manure plowed under, 150 pounds 4-12-4 fertilizer in hill; wheat: 400 pounds 2-14-4 fertilizer; [4] lime to give soil reaction of pH 7.0; tile drained.	73.7	60.8		31.5	[5] 3.1	35.25	3.00	32.25
Lafayette, Ind.; Miami, Crosby, and Brookston silt loams; 13 years' data from plot 12, grain and livestock system experiment.[6]	Corn: manure [7] and 100 pounds 2-12-6 fertilizer in hill; wheat: 300 pounds 2-12-6 fertilizer; tile drained.	70.1	..	31.0	35.8	[8] 2.5	35.18	2.00	33.18

[1] Values employed: Corn, $0.60 per bushel; wheat and soybeans, $1; oats, $0.40; hay, $10 per ton.
[2] For fertilizers and lime, figured at present market price.
[3] Salter (*288, p. 85*).[2]
[4] Prior to last 8 years, 400 pounds of 0-16-0 fertilizer was used on both corn and wheat.
[5] Mixed alfalfa, clover, and timothy.
[6] Indiana Agricultural Experiment Station (*178*).
[7] Manure equal to weight of crops excluding wheat grain.
[8] Alfalfa.

The beneficial effects of manure upon the soil are well known to gardeners and greenhouse men, who are accustomed to use relatively enormous applications. With the limited amounts of manure available on general farms, such marked changes in soil properties are not seen. However, there is no doubt that the physical effects of incorporating coarse organic matter with the soil are important in moderate field applications. The protection from beating rains and evaporation afforded by manure used as top dressing noticeably improves the tilth of heavy soils and reduces erosion; the increased root and top growth of fertilized crops has similar effects.

The maintenance of the original humus content of the soil is not merely a matter of incorporating organic matter, such as straw, cornstalks, etc. The composition of these materials is widely different from that of the stabilized soil humus, which represents the accumulation from centuries of biological activity in the virgin soil. Such materials as straw contain relatively less nitrogen in proportion to carbon, in the form of easily decomposed carbohydrates, than does humus; the carbon-nitrogen ratio (C/N) is about 50 to 1 as compared to 10 to 1 for humus.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

When unhumified organic matter with a wide carbon-nitrogen ratio undergoes biological decomposition, the organisms that carry on the processes have a certain requirement for nitrogen and other fertility elements, which they build into their cell substance just as higher plants do. There is not enough nitrogen in the straw to supply what the organisms need to decompose this amount of raw material. They must get more nitrogen from the soil, and therefore they compete with the crop for the supply in the soil. This explains the bad effect often noted from plowing under straw or fresh manure containing excessive straw. Experiments have shown that this can be prevented by adding 0.5 to 1 percent of available nitrogen, based on dry weight of straw. Good manure, on the other hand, contains sufficient quick-acting nitrogen to take care of the decomposition of a normal amount of straw and in addition to furnish some for the immediate needs of the crop. All this points to the necessity of conserving the nitrogen of farm manure, for this element is both a direct plant food and essential to the formation of humus.

It is well established that certain organic constituents of manure are of value in promoting plant growth; creatinine is an example (*360*). β-indolylacetic acid, which has a powerful effect in stimulating root growth, has been isolated from urine and no doubt occurs in manure; the chemically related skatole and hydrogen sulphide, which are largely responsible for the foul odor of manure, have been credited with growth-stimulating properties.[3] In addition to these direct effects of organic constituents of manure, there are possible indirect effects; the reducing action of manure decomposing in the soil undoubtedly aids in making available iron and manganese, present in all soils but sometimes unavailable under excessively oxidizing conditions. The soluble organic matter supplied by manure is believed to aid in keeping iron and phosphates in solution, thus promoting their movement through the soil, and also to have a favorable effect upon mineral colloids.

THE MANURE PRODUCTION PROCESS

It has long been known by practical farmers that manure from different classes of animals varies in value; manure from grass-fed animals, growing stock, and milk stock is less rich than that from animals being fattened or from work animals liberally fed on concentrates. This was explained almost a century ago by the work of the pioneer agricultural chemists, who showed that the constituents of the excreta are derived from the food. Passage through the animal can add nothing to the total amount of the fertility elements. Growing animals and those producing milk utilize considerably more of the nitrogen, phosphoric acid, calcium, etc., of their food for flesh, bone, and milk than is retained by mature stock, on maintenance rations, working or even fattening. In the latter cases, the feeding must be

[3] Good manure is a nitrogenous fertilizer. Hence, it increases the protein content of nonleguminous crops, and when properly supplemented to bring the plant foods into balance it improves crop quality in general. Claims that grain or forage grown with animal manures are superior in nutritive qualities have been made; a certain analogy between the action of growth stimulants upon plants and hormones and vitamins upon animals is obvious, and it has been suggested that there is a cycle of transformation from one to the other. Increasing knowledge of the chemistry of these substances makes such a theory seem improbable, but it is more reasonable than the "anthroposophic" doctrine prevalent in parts of Europe, which denies any beneficial effect upon plant growth or crop quality from mineral fertilizers but attaches great importance to mysterious vital forces in animal manures, as well as to moonlight and starlight (*304*).

liberal to supply the carbohydrates and proteins necessary for a high transformation of energy from food into work or stored fat, but less of the nitrogen and minerals are retained in proportion to the greater amount of food.

The constituents of feedstuffs actually utilized are the carbohydrates and fats for energy, the nitrogenous proteins for both energy and tissue building, and the mineral constituents for bone and milk and regulating body processes. Digestive processes are dependent upon the action of enzymes secreted by the animal, which dissolve and break down the complex molecules of food materials into simpler soluble substances—carbohydrates to sugars, proteins to amino acids, fats to fatty acids. In this state the food can diffuse into the blood and be carried to all parts of the body. Some carbohydrates, such as cellulose, and nonprotein nitrogen compounds (amides) are not made available by the processes of digestion as such, but can be utilized by ruminants with the aid of bacteria living in the intestinal tract. These substances are turned into sugars by enzymes secreted by the bacteria, or they are built directly into the protoplasms of the bacteria and then digested by the animal.

Constituents too resistant to be dissolved in these ways, insufficiently chewed, or too well protected by indigestible matter simply pass through the animal and are rejected in the feces. The latter, then, contain little that has really been a part of the animal; they consist of undigested material taken as food and of bacterial cells, living and dead, which make up 20 to 30 percent of the solid excrement and contain half or more of its nitrogen content as proteins.

The most resistant constituent of feedstuffs is the woody substance lignin, although much cellulose and related carbohydrates also escape digestion. Only about half the protein of timothy hay, a typical low-grade roughage, is digested as compared with 80 percent of that in a concentrate like cottonseed meal. Also, as the level of protein feeding is raised beyond a certain point, the protein is less effectively digested and more passes into the feces. It has recently been established by Waksman and Iyer (*446*) that lignin combines directly with proteins to form a humus complex apparently identical with that of the soil; it is not surprising, therefore, that more than a quarter of the organic matter in cow dung is true humus, as found by Siegel (*359*). The nitrogen compounds of dung are insoluble and have already resisted digestion, hence they cannot be very available as fertilizers.

The waste products of carbohydrate metabolism are excreted through the lungs, as carbon dioxide, and those of protein metabolism through the kidneys, as the nitrogen compounds urea and hippuric acid. Both are very readily attacked by micro-organisms common in dung and soil, the nitrogen being converted to ammonium carbonate, a form in which it is highly available for immediate use by plants. Urine also contains most of the potash originally in the food, but the phosphoric acid and calcium are found mostly in dung.

The composition and amounts of excrements produced by farm animals are shown in table 2. From these data, it is seen that there are considerable variations in composition as well as in amounts produced. The dung of horses and sheep is drier and the urine of these animals more concentrated than is the case with hogs and cattle.

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Manure from horses and sheep is not easily compacted; consequently it ferments or heats more readily than that of hogs and cattle, which is commonly called cold by farmers. The urinary secretion of birds is semisolid and is voided mixed with the feces, so that hen manure is a very concentrated product. The urine of hogs makes up a greater proportion of the total excrement and is notably low in nitrogen and high in phosphoric acid. These differences are in part physiological peculiarities, in part attributable to the nature of the food. Animals of the same kind fed more concentrates excrete more of the fertility elements because the food contains more.

Table 2.—*Average daily amount and composition of solid and liquid excrement of mature animals* [1]

Kind of animal	Daily production per animal		Composition of fresh excrement									
			Dry matter		Nitrogen		Phosphoric acid (P_2O_5)		Potash (K_2O)		Lime (CaO)	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
	Pounds	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Horses	35.5	8.0	24.3	9.9	0.50	1.20	0.30	Trace	0.24	1.50	0.15	0.45
Cattle	52.0	20.0	16.2	6.2	.32	.95	.21	0.03	.16	.95	.34	.01
Sheep	2.5	1.5	34.5	12.8	.65	1.68	.16	.03	.23	2.10	.46	.16
Hogs	6.0	3.5	18.0	3.3	.60	.30	.46	.12	.44	1.00	.09	.00
Hens	.1	------	35.0	------	1.00	------	.80	------	.40	------	------	------

[1] Data for daily production and for nitrogen, phosphoric acid, and potash content (except hen manure) are taken from compilation of Ames and Gaither (*13*). Data for lime content are from Ruschmann (*328*). Composition of hen manure is that given by Van Slyke (*440*).

LITTER AS A CONSTITUENT OF MANURE

Bedding material or litter is necessary to keep stabled stock clean and comfortable and conserve values in the manure. As a constituent of manure, the ideal litter should have the following characteristics:

(1) It should be easily obtainable and cheap.

(2) It should have high absorptive power for liquids so as to be economical in use and prevent loss of urine.

(3) It should not be dusty—an especially important point in dairies and poultry houses—and it should be as nearly sterile as possible, or at any rate a poor medium for the growth of micro-organisms.

(4) Fixing capacity for ammonia and potash is desirable, to prevent losses.

(5) Available plant food in the litter adds to the value of the manure.

(6) A high content of cellulose and similar carbohydrates easily attacked by micro-organisms is in one respect undesirable, as this promotes fermentation and heating, favoring both the loss of ammonia by volatilization and its transformation to less available organic forms. On the other hand, with proper fermentation, carbohydrates produce acids that tend to increase the production of ammonia and to favor its conservation under practical conditions of manure handling.

(7) The material should not be excessively coarse, as this detracts

from the animals' comfort, reduces absorption, and prevents proper compaction and easy handling of the manure.

(8) Litter should remain well in place and not be too readily kicked aside. The characteristics of common litter materials are shown in table 3.

Table 3.—*Characteristics of litter materials* [1]

Material	Litter required to absorb 100 pounds of liquid	Nitrogen held per ton of litter [2]	Content of fertilizing ingredients per ton of air-dry material: Nitrogen	Phosphoric acid	Potash	Carbohydrate activity
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
Wheat straw	45	4.5	11	4	20	High.
Oat straw	35	7.1	12	4	26	High.
Rye straw	45	3.4	12	6	17	High.
Chopped straw	20–30	----	----	----	----	High.
Cornstalks (shredded)	25–35	5.3	15	8	18	High.
Sawdust	25	0	4	2	4	Medium.
Wood shavings	25–45	0	4	2	4	Medium.
Spent tanbark	25	----	10–20	----	----	Medium.
Leaf litter	25–60	[3] 26.6	16	6	6	Medium.
Peat moss (sphagnum)	10	40.0	16	2	3	Medium.
Peat (sedge and woody)	15–25	30.0–60.0	20–60	2	3	Low.

[1] Compiled from various sources. [2] Fixing capacity for ammonia nitrogen. [3] Oak leaves.

Cereal straws are most used for litter because they are cheap and contain available plant food. They do not have a high absorptive capacity unless they are chopped, when they become objectionable because they do not stay in place. They are also dusty and have little capacity to fix ammonia and potash. Whole corn stover from which the animals have picked the edible parts has only cheapness and available plant food to recommend it, but when run through a husker-shredder, more is eaten and the remainder is considered equal to straw as bedding. Wood products are widely used in some districts, but they are poor in fixing capacity and in available plant food.

Fibrous sphagnum peat, or peat moss, is one of the best litters where it is obtainable at low cost; in absorptive and fixing power it is unexcelled, and it contains little readily decomposed carbohydrate. These factors, together with the strongly acid reaction, have a pronounced effect upon the course of fermentation of the manure, checking losses of nitrogen. Its remarkable efficiency in preventing loss of ammonia from fresh manure has been noted by Hall (*136*), and in this and other respects it cannot but add to the comfort of the animals. That this has a definite economic value was shown by Lemmermann (*216*), who reports that cattle bedded with peat gained more weight than those bedded with straw; the explanation offered is that the peat made such a comfortable bed that more time was spent lying down, which requires 8 percent less energy than standing. However, practical trials with poultry at the Ohio Station (*196*) indicate that it becomes too dusty as the birds scratch it about. No trouble from this cause in dairy stables has been reported. Ruschmann (*328*) states that peat contains 1 to 9 million organisms per gram, as against 31 million in sawdust and 116 million in straw, and that up to 40 percent of the bacteria in milk have been traced to straw litter.

The Rotting of Manure

As it is ordinarily handled, profound changes occur in a manure heap. Fresh manure is an ideal breeding place for a multitude of organisms because of its high content of vegetable and animal wastes as sources of energy, its supply of suitable salts and water, and the generally favorable temperature and aeration. The organisms work over the materials, utilizing some and dissipating their energy as heat of oxidation in vital processes; what the firstcomers reject is consumed by others in successive phases of the cycle until at length there is left only humus—that ill-defined product of decay so slowly decomposed that it may be considered almost stable—together with such mineral elements as may have survived the numerous opportunities for loss.

The desirability of rotting manure before it is incorporated with the soil is frequently emphasized, because otherwise it is supposed to be too hot and quick in action. Such a belief may be supported by practical experience; for example, the effect of well-rotted manure applied in large amounts, as to a garden, is undoubtedly better than that of an equally extravagant manuring with fresh material. One reason is that the rotted manure has lost much of its quick-acting ammonia as well as so much organic matter that the phosphoric acid and potash remaining are relatively increased and the fertilizer action is in better balance. However, this result is obtained at heavy cost in losses of nitrogen and organic matter, and too often of potash also. It would be more economical to use less fresh manure and supplement it with phosphoric acid and potash, which would result in better utilization of the available nitrogen. Even with very strawy manure, the advisability of rotting may be doubted; supplemental fertilizer nitrogen will enable the organic matter to undergo normal humification in the soil without causing the crop to suffer.

A second reason for the unfavorable action of strawy manure is that when it is turned under connection with the subsoil is broken and the topsoil dries more rapidly from the increased aeration. For some crops on heavy soils, such as potatoes, this action of coarse organic matter is favorable (*287*). The greatest advantage of rotting is that when properly conducted it increases the production of acids by the fermentation of carbohydrates, thus removing those most active without too great loss of organic matter, and at the same time decreasing the tendency to lose ammonia in storage and on application to the field. Inasmuch as there is less tendency toward loss of ammonia with absolutely fresh manure, if this could be applied to the field daily there would be slight justification for allowing it to ferment. There are numerous reports of practical field tests showing superiority of fresh over fermented manure.

LOSSES OF FERTILIZER MATERIALS FROM MANURE

Losses start with failure to utilize the value of urine in manure resulting from insufficient bedding, seepage through stall floors, or drainage from storage. The proportion of total fertilizing elements in urine and their value compared with that of the total excrement is shown in table 4. The urine annually produced by one dairy cow is equivalent to commercial fertilizer costing $9 and properly used will

increase the value of crops over the unmanured yield by two to four times that amount. When animals are kept on earth floors, quantities of litter otherwise ample may not suffice to prevent the liquid entering the earth, owing to its superior capillary pull. At the Ohio Station, a direct comparison with two lots of steers, one kept on compacted earth, the other on a cement floor, indicated that one-fourth of the liquid excrement was lost with the former, reducing the value of the manure by one-sixth (*13*). It was calculated that the saving in two feeding periods of 6 months each was sufficient to pay for the floor.

Table 4.—*Percentages of fertilizing elements in urine of various farm animals and value in relation to total excrements*

Kind of animal	Nitrogen	Phosphoric acid	Potash	Value [1]	Kind of animal	Nitrogen	Phosphoric acid	Potash	Value [1]
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
Horses	35	0	58	50	Sheep	63	4	86	75
Cattle	53	5	71	65	Hogs	32	13	55	40

[1] Calculated from data of Ames and Gaither (*13*) with dung nitrogen valued at one-fourth the figure for urine nitrogen, at present fertilizer prices.

Leaching by rain may be even more serious, as the total soluble matter is thus removed. A single heavy rain of 1½ inches is equivalent to about 1 gallon of water per square foot, most of which will percolate through manure in shallow piles and remove a large part of the soluble material in doing so. The possible losses are very considerable, as shown in table 5.

Table 5.—*Proportion of fertilizing elements and organic matter of farm manures, including litter, that is soluble in water* [1]

Kind of animal	Organic matter	Nitrogen	Phosphoric acid	Potash	Kind of animal	Organic matter	Nitrogen	Phosphoric acid	Potash
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
Horse	5	53	53	76	Steer	7	56	36	92
Dairy cow	7	50	50	97	Sheep	7	42	58	97

[1] From data of Ames and Gaither (*13*).

Nevertheless, if manure must be stored, it does not necessarily follow that it should be under cover; with a properly compacted high heap on a relatively small base, the rainfall may be just sufficient to keep the manure properly moist and in optimum condition for conservation of value if there is no loss by leaching. That at the top will be leached, but will serve as a seal to prevent access of air to lower layers, in which the fertility will be retained. Under these circumstances, protection for the sides of the heap is more important than for the top. The Württemberg dungstead, used in Germany, a special structure tightly built of boards for manure storage, is not usually roofed, although the contents may be covered with about a foot of earth if it is to be left undisturbed (fig. 1). The only similar structure

on an American farm is the silo, and the same principles apply to the conservation of manure in the one as to the preservation of a green crop in the other—exclude air by compaction to encourage acid fermentation and retain everything possible.

Access of air to the interior of a mass of manure results in excessive heating and losses of organic matter and nitrogen. The conditions of fermentation are unfavorable to the accumulation of organic acids to hold ammonia, and the latter escapes with the air circulating through the mass, if, in fact, it is not completely decomposed by nitrification-denitrification reactions. Experiments in England by Russell and Richards (*329*) show the losses in 3 months' winter storage from loose

Figure 1.—Württemberg dungstead at Agricultural High School, Hohenheim, Germany. Each chamber holds about 10 cubic yards of manure; the one at the right, in section for demonstration only, shows the preferred construction with boarded walls as well as the cheaper poles used elsewhere. (Courtesy K. Maiwald, Hohenheim.)

and compacted heaps of both cow and steer manure sheltered and exposed to the weather. Heating of compacted cow manure under shelter was slight—maximum temperature 50° F.—with loss of only 4 percent of dry matter and no nitrogen. The same material loosely piled outside suffered losses of 21 and 25 percent, respectively, with a maximum temperature of 70°. Losses from the drier and richer steer manure were more difficult to control; loose heaps under cover and in the open heated to 160° and 132°, respectively, with somewhat greater losses in the latter case—of 41 percent of dry matter and 27 percent of nitrogen. Compaction and covering reduced these losses considerably, but they still remained high. If the two kinds of manure had

been mixed, compacted, and covered, the total loss would no doubt have been reduced, because compaction would have been more effective. Many experiments could be cited to show that summer storage results in greater heating and losses than winter storage.

The losses discussed are more or less controllable by care in collecting and storing manure, but they do not complete the list. Fermented manure spread upon the field is subject to important losses of ammonia by direct volatilization into the air, which may be very rapid indeed in warm, dry, and windy weather. The better the quality of the manure, the greater the possibility of losses in application, so that the effect of previous care may be largely nullified from causes too little appreciated.[4] At the Wisconsin Station, Heck (*155*) measured the rates at which ammonia was lost from fermented cow manure under different conditions. The fact that almost one-half to three-quarters of the ammonia (one-fourth to one-third of the total nitrogen) was lost within periods of 12 hours to 7 days under conditions such as may occur in practice, namely, at 68° F. with an 8½-mile wind, indicates the importance in causing serious losses of such factors as air circulation in loose heaps, storing in places exposed to wind, forking over fermented manure, and permitting it to dry before plowing under.

Chemical Agents for Reducing Losses

The addition of antiseptics to prevent fermentation losses has been proposed, but in general such as are effective are objectionable. Fixing agents for ammonia have been more generally advocated; gypsum (calcium sulphate) has been used for many years, although probably as much for reduction of the ammoniacal odor in stables as from intention to increase the value of the manure.[5] The carbonate produced makes the reaction reversible, hence gypsum and similar salts of calcium and magnesium cannot prevent loss of ammonia by volatilization in drying. Similar use of superphosphate, which consists principally of monocalcium phosphate and calcium sulphate, has been enthusiastically advocated by some American writers and has much to recommend it; manure is deficient in phosphoric acid and requires supplementing with it for realization of the full value of the nitrogen and potash. Midgley (*257*) has shown that superphosphate is more effective in fixing ammonia than either gypsum or monocalcium phosphate alone, because no calcium carbonate is produced and the reaction is not reversible.[6]

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[4] Ammonia is a weakly dissociated volatile base and in combination with the organic acids occurring in manure, which have similar properties, it is not as firmly held as it would be by a strongly dissociated mineral acid such as sulphuric. There is an appreciable vapor pressure of both ammonia and the acid over solutions of the ammonium salts of these weak acids—that is, the salts are volatile upon drying. Absolutely fresh animal excrements contain practically no ammonia. The first rapid phase of fermentation of urea, etc., produces ammonium carbonate or bicarbonate, and of all the series of acids produced in fermentation, carbonic is the weakest and most volatile, with practically no ability to hold ammonia against loss from drying or exposure to air. The less volatile acids produced by later fermentation of carbohydrates and proteins are more effective in this respect, but the ammonium salts of all are decomposed by drying. The Danish investigator Jensen (*187*) found that fermented urine absorbed by filter paper and exposed to a current of air lost 61 to 63 percent of its ammonia content in 30 minutes; in still air, the loss was only 18 percent in the same time. At ordinary temperatures, the rate of loss was observed to more than double for each increase of 10° C. (18° F.).

[5] The reaction is—

$$CaSO_4+(NH_4)_2CO_3 \rightleftharpoons CaCO_3+(NH_4)_2SO_4$$

(Calcium sulphate+ammonium carbonate=calcium carbonate+ammonium sulphate)

$$2\ CaSO_4+CaH_4\ (PO_4)_2+2\ (NH_4)_2CO_3 \rightarrow$$

(Calcium sulphate+monocalcium phosphate+ammonium carbonate

$$Ca_3(PO_4)_2+2\ (NH_4)_2SO_4+2\ H_2O+2\ CO_2$$

tricalcium phosphate+ammonium sulphate+water+carbon dioxide)

Since the proposal is attractive, it may be well to discuss briefly its economics. On the basis of Midgley's data, the requirement for maximum preservative effect is 2 to 2½ pounds of 20-percent superphosphate per horse or cow stabled 24 hours. One ton of 20-percent superphosphate, costing \$23.50 in 1937, should [illegible] pounds of ammonia nitrogen worth \$12.18. In the process, however, all of the available phosphoric acid of the superphosphate is changed to insoluble tricalcium phosphate.[7] On nearly neutral soil this loss in value of phosphoric acid may cancel the possible saving in ammonia. If the treated manure is applied at the usual rate, 8 tons to the acre, it will carry nearly 500 pounds of superphosphate, or two to three times the amount farmers are accustomed to use for most crops. Furthermore, superphosphate mixed with manure cannot be applied in the hill or row, which has repeatedly been shown to be the most efficient method. Thus, the practicability of this treatment for general use may be questioned. It would appear to be most promising when the manure is to be applied to moderately acid soils for certain vegetable crops requiring considerable amounts of both nitrogen and phosphoric acid or for top dressing grass or small grains in winter.

Acids in general are both antiseptics, inhibiting bacterial activity, and ammonia fixers; Henglein and Salm (*159*) recently showed that addition to manure of sufficient 5-percent sulphuric acid to increase the acidity to pH 5.0 was effective. Niter cake (sodium bisulphate) has at times been obtainable as a waste product at low cost and should be as good, with the further advantage that it can be handled as a solid. Drenching manure with waste whey to acidify it is practiced to some extent in Sweden (*328*). Juice drained from a silo might be used in the same way. Recent developments in the direct production of phosphoric acid anhydride (P_2O_5) at low cost suggest that this material or possibly metaphosphoric acid may soon be available for addition to manure in the stable. Both are solids and can probably be produced in granular form convenient for use. Either would be effective in acidifying manure, and their phosphoric acid would remain available to plants, although some of the other objections to superphosphate would still apply.

When bedding must be purchased, the superiority of acid peat moss, both as litter and as preservative of values in manure, entitles it to consideration. Considerable amounts of the baled material are now imported, and it could be produced in the United States. According to Ruschmann (*328*), it is the only litter suitable for use when both urine and dung are to be handled together.

Other Methods of Preventing Losses

The total prevention of losses is not possible. Even with daily spreading, the fresh material must lie exposed for some time, permitting volatilization of the ammonia that is rapidly developed in the first stages of fermentation, although such loss may be reduced by the use of acid peat litter or superphosphate. No exact figures are available, but it is inferred from data obtained in a 40-year field experiment at

[7] The latter has been shown by Salter and Barnes (*334*) at the Ohio Station to be only 66 percent as available as the phosphoric acid of superphosphate for wheat on soil at pH 5.5; this figure is reduced to 47 and 19 percent on soil at pH 6.0 and 7.0, respectively.

the Ohio Station that losses from daily spreading may average very little less than those that occur with a good method of storage, spreading under favorable conditions, and plowing under promptly.

There is no doubt that losses can be minimized if the liquid excrements are handled separately, using water to moisten the dung as necessary, but the economy of such a procedure may be questioned. Such separate handling is common practice in parts of Europe but is practically unknown here, although use of the method is increasing where it has been tried, as in Oregon (*394*). Liquid manure is easily protected from losses by storage in tight tanks with a covering of oil, and may be applied to the field with a special drill without exposure to the air. The extra investment and labor required would often cancel the saving in nitrogen, although other advantages, such as enabling rotational pasturing without fencing by spreading liquid manure on grass (*394*), may lead to the adoption of this method.

The principle to be applied in manure storage to ensure the smallest losses possible without resort to chemical preservatives is simple—compact the manure to exclude air. This prevents heating with its attendant losses, ensures acid fermentation, and prevents leaching and drying. The easiest method of compacting manure is to let the animals do it—the well-known deep-stall method of accumulating manure under fattening stock is very effective in conserving values. Some sanitary regulations applying to the production of market milk prevent the use of the simple deep-stall for dairy cows, but the essential requirement of compacting the manure under cover at the legal distance from the quarters for milk cows may be met.

Slipher (*361*) suggests several practical plans for manure storage at the end or side of the barn adjacent to horse stalls, and for covered feed lots in which the manure is accumulated under the animals. A rectangular cemented pit in the barnyard, with one side a ramp so that the spreader may be backed in and animals may enter at will to tread down the manure, is practical on any farm. An inexpensive roof may be provided by building a frame of sufficient height and strength to support the strawstack over the pit. A covered driveway with trolley manure carrier from stable to pit, under which the spreader stands so that fresh manure can be dumped into either the spreader or the pit, is suggested. Gutters for stable and piggery drainage discharge into the pit, if urine is to be stored with the solid manure. It may sometimes be necessary to supply extra water to moisten the manure, but the walls of the pit should exclude all surface drainage. Too much water is objectionable and is not a substitute for solid packing. The ideal condition is to have just sufficient moisture to facilitate compaction.

The modern manure spreader is an effective implement for distribution, tearing the manure masses apart and spreading the material more thinly and evenly than is possible with a fork. The greater exposure to air resulting from this effective spreading is probably a factor in reducing losses from absolutely fresh manure; if the weather conditions cause rapid drying, ammonification may be checked sufficiently to reduce losses considerably, and the soluble nitrogen will be washed into the soil by the first good rain. On the other hand, with fermented manure this good distribution is equally effective in encour-

aging losses of preformed ammonia through drying. If fermented manure can be spread not too fine in cool and moist weather without much wind and the spreader is followed by the plow or disk harrow as closely as possible, the conditions will be favorable for minimum losses.[8] When manure is used as a top dressing for its protective effects mainly, such as improvement of the stand of a legume or mixed meadow seeding (*395*), it is evidently best to use fresh manure and in any event to spread before a rain in cool weather, in order that as much as possible of the soluble nitrogen may be washed into the soil before it can be lost from drying.

Recent studies at the Vermont Station (*258*) have shown that freezing acts like partial drying in causing loss of ammonia from fermented manure, also that treatment with superphosphate is not very effective in preventing such loss. Hence, spreading fermented manure in freezing weather is objectionable. Spreading on snow over frozen ground also carries the risk of heavy loss by surface wash if the snow melts rapidly. The old plan of hauling to the field and leaving for a considerable time in small piles is to be condemned strongly, for the conditions are highly favorable for losses and wherever there has been a pile there will be a rank spot caused by leaching into the soil at that point. If field storage is considered necessary, the heaps should be large, well compacted, and if possible covered with earth.[9]

It is a general rule that fertilizers (with some important exceptions, as, for example, calcium cyanamide) should not be applied much in advance of planting, in order to minimize losses from leaching and fixation in unavailable form by the soil. The same principle applies to manure, even though there is some basis for the belief that with fresh manure containing much straw a month or two between the time of incorporation and of greatest nitrogen requirement of the crop may be advantageous, giving time for carbohydrates to decompose and nitrogen again to become available.

Iverson (*179*) reports data from many Danish field experiments continued for periods up to 16 years with various crops, and concludes that application immediately before planting is best; in one long-time experiment with mangels seeded shortly after the middle of April, the relative efficiencies of manure plowed under at different dates preceding averaged:

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[8] The extent to which ammonia is lost from good manure by drying before it can be plowed under seems not to be generally appreciated by American farmers. Iverson (*180*) found the following losses of nitrogen from manure spread at different seasons:

Loss	December	March	April
	Percent	*Percent*	*Percent*
First 24 hours	2	3	21
First 4 days	15	10	29

The results of 34 field experiments with oats and root crops with fermented manure spread and plowed under after various intervals indicated an average loss of 15 percent from 6 hours' exposure, increasing to 27 percent in 24 hours and 42 percent in 4 days.

[9] Danish work indicates that if manure spread and plowed under immediately is rated 100 in crop-producing ability, that spread and plowed under 2 days later is 71, as compared with 80 for 2 days' field storage in piles. For 2 weeks' time, the figures are 49 and 55, indicating that field storage is almost as bad as delay in plowing under after spreading. Such losses from remade piles are not surprising, for each time the manure is disturbed the advantages of previous compaction are lost and heating is started anew.

	Percent		Percent
October 15	58	February 1	83
November 15	68	March 1	75
December 15	84	April 15	100

These figures refer to the first-year effects; there were no significant differences in later results, indicating that losses from early applications were from the quickly available nutrients in the manure. These experiments were mainly on sandy soils; some on loamy soils showed smaller differences and there were considerable variations from year to year. It would appear that on heavier soils, or with manure that has already lost much of its immediate value from heating and leaching, more consideration may be given to convenience in time of application.

The desirability of placing plant nutrients within easy reach of the roots of seedlings and reducing the chance that they may be leached beyond the zone in which they are most effective, suggests that local placement of manure may have advantages. Manure in the row produced 82 pounds more seed cotton than when broadcast and harrowed in, in a 2-year test at the South Carolina station (*363*). But Iverson (*180*) reports heavy losses from manure harrowed into plowed soil, compared with that plowed under; Stevenson and Brown (*386*) at the Iowa Station obtained the best results from manure disked into plowed soil. Heck (*156*) observed more rapid nitrate development and a slight increase in nitrogen recovery from manure disked in, although the yield was a little better with plowing under in the single field test with barley. Trouble from weed seeds may be less with deep burial by plowing, but the most important factor seems to be effective covering.

It is frequently recommended that manure be thoroughly disked into the surface soil before plowing, and if covering can be more quickly effected in that way, the procedure no doubt has merit. Also fresh manure intimately mixed with soil may have more of its available nitrogen absorbed thereby, so that plant roots are better able to secure nitrate in competition with organisms decomposing carbohydrates in the manure. The question of manure placement should be further investigated. Top dressing with manure is effective in increasing the stand of hay crops seeded with winter wheat, but field experiments at several experiment stations all show larger increases in the grain crop from incorporation by plowing.

PRACTICAL HANDLING OF MANURE

Maximum returns from manure can be obtained only by applying it with due recognition of the following facts:

(1) Manure is relatively deficient in phosphoric acid. Allowing for the low value of the greater part of the nitrogen in manure, a ton is equivalent to 100 pounds of a 3–5–10 or 4–5–10 fertilizer, which will at once be recognized as an unbalanced formula for legumes, wheat, and many other crops, but better adapted to corn, sugar beets, potatoes, and tobacco. Few fertility practices have proved more generally profitable than reinforcement of manure with a phosphatic fertilizer. From the long-time work at the Ohio Station, it is concluded that the average return over cost from 320 pounds of 16-

percent superphosphate used with 8 tons of manure for corn in a corn-wheat-clover rotation has been at the rate of 412 percent; even greater returns might be expected when the manure is applied to corn and the phosphate to wheat in the rotation.

(2) At the commonly used rate of 8 tons of manure to the acre for corn, about 200 pounds of plant nutrients are applied, equivalent to half a ton of a 20-unit mixed fertilizer. As with other fertilizers, the action of manure is subject to the law of diminishing returns, and with an increasing rate the profit per ton applied decreases. A study of data obtained at the Ohio Station indicates that this is less true of the long-time or residual effects of manure than of the immediate or first-year effects.[10] Other experiments support the opinion that lighter applications of manure are equally effective when supplemented by a carrier of available phosphoric acid. In general, it appears that the returns from a given quantity of manure are greater with lighter application to a larger area.

(3) In preceding discussions of storage losses, it has been noted that these are more serious in summer than in winter. It is plain, therefore, that manure should be applied for spring crops rather than held in storage for fall application, as pointed out by Thorne (*401*). With spring crops following sod, there is the further advantage of greater ease in spreading and usually more favorable weather for application without excessive losses from drying.

(4) Although top dressing with manure increases loss of available nitrogen, there may be compensating advantages such as improvement in stand of legumes or grass seedings which make the practice profitable.[11]

(5) Hill or row application of fertilizers has been conclusively demonstrated to be more efficient than broadcasting, which seems to be the only practical method with manure. The principal reason is that localized application results in a greater concentration of nutrients available at an early stage of growth. This is most needed with spring planting on poor soils.[12] Often, a supplementary application of fertilizer in the hill or row is much more economical than the excessive amount of manure that would be required to meet equally well the early demands of the crop.[13]

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[10] In one experiment, the second 10 tons of a 20-ton application of manure is credited with increases of 124 pounds of tobacco, 4.5 bushels of wheat, and 572 pounds of clover hay, total value of $19.26 per rotation. Another plot in this experiment received 400 pounds of 16-percent superphosphate with 10 tons of manure; yields indicated that this extra phosphoric acid produced increases of 160 pounds of tobacco, 5 bushels of wheat, and 698 pounds of clover hay, total value $24.30. The second 10 tons of manure is estimated to carry 50 pounds of phosphoric acid, or 78 percent of that in the 400 pounds of superphosphate. The increase produced by this manure was 79 percent of that credited to the supplement of superphosphate, from which it is concluded that the effect of the former was largely due to the phosphoric acid supplied, the first 10 tons having furnished all the nitrogen and potash needed.

[11] At the Ohio Station, the average increase in yield from 20 crops of winter wheat produced with half a standard application of manure plowed under in early fall has been 4.4 bushels. From the same amount used as top dressing in December it has been only 0.9 bushel. The average increases in 18 clover crops seeded with the wheat have been 842 and 1,604 pounds, respectively. The value of the crop increases from using the manure in these ways has been $8.59 and $8.89, respectively. The Indiana Station (*464*) reports 15 years' data from an experiment comparing different methods of applying manure to a corn-wheat-clover rotation. By one method, only corn was manured, at a rate of 6 tons per acre. By another method, 4 tons of manure was applied to corn and 2 tons as a winter top dressing to wheat. The average increases for the two methods were 13.2 and 12.7 bushels of corn, 4.5 and 6.5 bushels of wheat, and 283 and 752 pounds of hay, respectively, and the total increased values of crops from the two methods were $12.46 and $15.64.

[12] With corn, an application of 200 pounds per acre of 20-unit fertilizer gives a concentration of nutrients within a 4-inch radius of the hill seven times as great as with 8 tons of manure plowed in, although the latter furnishes five times as much fertility.

[13] A 5-year test at the Ohio Station with 8 tons of manure applied for corn indicated increases of 11.9 bushels of corn and 6.3 bushels of oats following; an additional 200 pounds of 4-12-4 fertilizer applied in the hill for the corn further increased the yields by 8.1 bushels of corn and 2.1 bushels of oats over manure alone. This was on soil producing 30 bushels of corn and 25 bushels of oats without manure or fertilizer.

(6) A general rule with manure as well as fertilizers is that greatest profit may be expected from application to crops of high acre value. In the potato-wheat-clover rotation at the Ohio Station, 8 tons of manure applied to potatoes produced total increases valued at $58.30; the same amount applied to wheat returned only $48.95. Results at the Pennsylvania Station (*455*) indicate that manure applied to cropped land produced over 50 percent more digestible nutrients than when applied to pasture. However, on farms producing much manure, application of a part to pastures may result in greater total returns than can be obtained from excessive application to cultivated land. Grass makes good use of nitrogen, hence fresh or properly preserved manure is best, spread in cool and rainy weather to minimize losses. Strawy manure or that which has lost much ammonia in rotting but has not been leached is satisfactory for legumes. Animals avoid freshly manured grass, hence spreading should be on that part of the pasture most in need of a rest from grazing.

(7) The returns from a ton of manure applied to poor land may be expected to be greater than from an equal quantity applied to land already producing well, provided the poor land is not unproductive for some reason other than lack of fertility. With a field containing some parts more worn than the rest, liberal manuring of the poor spots will effect a notable improvement in uniformity.

In planning the use of manure in a rotation, the foregoing factors should be considered. In general farm rotations, the successful growth of sod legumes—alfalfa, clovers, etc.—is so important to economic production and soil conservation that wherever difficulty in getting a stand is experienced, the first use of manure might well be for a light top dressing, 2 to 4 tons to the acre, in winter or immediately after spring planting. If a good stand can be obtained without this measure, it offers no advantage. Corn responds well to manure; 6 to 8 loads to the acre with moderate fertilization in the row or hill may be expected to be more profitable than larger applications, if additional manure can be used to advantage elsewhere. For wheat following manured corn the next or third year, a high phosphate fertilizer is better than manure except on light sandy soils; application to grass or alfalfa in the second or later hay year is better than manuring wheat.

MANY different kinds of organic material are used or might be used on farms to add to the organic-matter content of the soil. The most important of these are various plant wastes and peat. It is possible to use these materials rightly or wrongly, depending on the soils and the crops grown. This article discusses the limitations of organic amendments as well as their uses.

The Nature and Use of Organic Amendments

By Irvin C. Feustel [1]

THE application to soil of organic matter other than that normally added in the form of crop residues or manures is seldom a part of general farm practice. Although such applications may improve the soil and increase crop yields, they are not, as a rule, justified by crop returns. The use of organic amendments for soil conditioning or for increasing the supply of humus is largely limited to special enterprises. Many specialized crops require methods of culture that are impractical or prohibitive in cost for general farming.

Organic matter may be needed for the establishment of optimum conditions for plant growth or for maintenance of desirable soil properties, particularly in cases where much or all of the root and top growth is constantly being removed from the soil. In preparing special soil media for greenhouse culture, flower beds, shrubbery, and lawns, the addition of substantial proportions of organic matter is frequently required to improve the physical properties of the soil, to stimulate the root development of cuttings, seedlings, or transplanted stock, to supply nutrients in forms in which they will become available slowly, or to produce suitable conditions for acid-loving plants.

Applications of the so-called organic ammoniates, such as cottonseed meal, castor pomace, or dried blood, increase plant growth primarily because of their content of readily available nitrogen. However, the quantities of these materials that can be used economically or with safety as nitrogenous fertilizers or fertilizer ingredients are negligible from the standpoint of increasing the content of organic matter in the soil.

Organic materials used to increase the supply of organic matter or humus in the soil and to obtain more or less prolonged physical or other

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effects are relatively inert so far as the immediate availability of nitrogen and other nutrients is concerned. The fertilizing value of such materials, however, is usually of some significance, depending on the nature of the material and its rate of decomposition. The gradual liberation of nutrients may in some cases be the primary objective. The beneficial effect of organic matter on the physical properties of the soil is more or less distinct from the benefit received from the liberation of plant nutrients, but it is very difficult to evaluate the two effects separately. Emphasis may be placed upon one or more of the various physical, chemical, or biological effects according to the requirements under given conditions.

FIGURE 1.—A compost pile. Composting is a means of reducing all sorts of vegetative and animal refuse to a more quickly utilizable condition for soil-improvement purposes. Any material, such as straw, spoiled hay, leaves, peat, muck, pine needles, and miscellaneous refuse can be made to serve as raw fertilizer material. The addition of manure and soil, along with certain fertilizer salts, to the pile makes for quicker decomposition and proper conservation of the fertilizer elements.

SOURCES OF ORGANIC MATTER

Farm manures have always been of great importance as organic amendments, but in modern times they have become increasingly difficult to obtain. Their use has been discussed in detail elsewhere and will be mentioned only incidentally in this section.

Composts of various kinds are prepared for local use and are a means of utilizing many waste materials to excellent advantage from both soil conditioning and soil-fertility standpoints. Fresh or undecomposed vegetable material rich in cellulose or other readily decomposable constituents is usually not satisfactory for direct use, because it greatly stimulates the growth of micro-organisms and may thus

temporarily render mineral nutrients in the soil unavailable for plant growth. The composting process effects a preliminary decomposition of the organic matter. In the preparation of a compost heap stable manure is commonly used in alternate layers with straw, leaves, sod, or other vegetable refuse (fig. 1). The mass is kept moist and occasionally turned. Absorbent material, such as straw or moss peat, used as poultry litter or animal bedding before composting, has considerable value as fertilizer material.

The addition of fertilizer chemicals to straw, leaves, cornstalks, or other similar refuse materials has been recommended and is frequently practiced in the preparation of composts. Decomposition is greatly hastened thereby and a satisfactory artificial manure may be prepared in 3 to 4 months. The material to be composted is spread out and piled in successive layers of 6 inches to 1 foot in thickness until a final height of 4 to 6 feet is reached. Each layer is wet thoroughly with water and receives a sprinkling of the desired fertilizer salts. The chemicals or chemical mixtures which have been recommended or used for this purpose by several of the State agricultural experiment stations, notably those of Iowa, New York, and Missouri, consist of approximately 60 to 70 pounds of ammonium sulphate, 20 to 30 pounds of superphosphate, 50 to 60 pounds of finely ground limestone, and 25 pounds of potassium chloride, as applied to 1 ton of dry straw. State experiment stations or agricultural authorities should be consulted for further details, however, in view of the fact that certain of these composting processes have been patented.

Peat and muck have become important sources of organic material and are available in commercial quantities. Their use can as yet be recommended only in a general way, as considerable experiment is needed to determine their suitability under varying conditions. Lack of proper information as to the fundamental character and the limitations of peat or muck has resulted in some disappointing experiences with them. It must be emphasized that these materials have little activity from a fertilizer standpoint; their chief value lies in the fact that the organic matter they contain is of a persistent nature so that whatever beneficial properties it may confer on the soil are prolonged.

Peat may be defined as consisting of the remains of aquatic, marsh, bog, or swamp vegetation preserved under water in a partially decomposed state. This natural resource varies considerably with respect to the vegetation of which it is composed, the stage of decomposition, the mineral content, and the degree of acidity. Fibrous varieties consisting of the remains of moss, reeds, or sedges are light brown or yellowish brown in color and are generally quite acid. Partially fibrous, woody, lumpy, or granular varieties vary in color from brown to black, and may range in acidity from very acid (pH 3.5 to pH 4) to moderately alkaline, depending upon the nature of the ground waters or subsoil underlying the deposit. The term "muck" is correctly applied to cultivated peat and to surface layers in an advanced stage of decomposition, in which the plant remains are for the most part no longer capable of being identified.

The total quantity of peat in the United States, exclusive of Alaska, calculated as air-dry material, has been estimated at 13,827,000,000

tons by the United States Geological Survey. Minnesota possesses the largest reserves, nearly 50 percent of the total. Wisconsin, Florida, and Michigan follow in order of importance.

The domestic industry first attained commercial importance in 1908, when eight companies were reported in operation and 23,000 tons of peat fertilizer filler were placed on the market. A peak of production was reached during the World War in 1917 and 1918 (table 1).

States producing the most peat in 1936 were New York and New Jersey, followed by Florida, Michigan, and Ohio in the order named. Ten other States also participated. About two-thirds of the total domestic tonnage was marketed as so-called peat humus and most of the remainder as reed or sedge peat. A small quantity of moss peat was also produced.

The greater proportion of the annual supply of peat is being imported from Europe and Canada (table 1). Previous to 1920, a negligible quantity was imported. Since then there has been an almost steady increase in the imports, except for the period 1931–33. The principal sources are Germany and Sweden, but Norway, Denmark, and Canada also supply appreciable quantities. The imports consist entirely of the sphagnum moss variety of peat, which is fibrous and spongy in character, light brown or yellowish brown, and highly acid.

Table 1.—*Quantity and value of peat produced in the United States*[1] *and imported,*[2] *1912–36*

Year	Quantity		Value		Year	Quantity		Value	
	Produced	Imported	Produced	Imported		Produced	Imported	Produced	Imported
	Short tons	*Short tons*	*Dollars*	*Dollars*		*Short tons*	*Short tons*	*Dollars*	*Dollars*
1912	47,380		228,572		1925	72,436	10,233	452,898	121,719
1913	33,260		197,200		1926	61,936	16,669	364,413	174,241
1914	47,093		309,692		1927		31,595		326,549
1915	42,284		288,537		1928		40,087		422,275
1916	52,506		369,104		1929		57,531		657,145
1917	97,363		709,900		1930		70,466		869,381
1918	107,261		1,047,243		1931		63,928		682,553
1919	69,197	464	705,532	16,345	1932		64,701		601,372
1920	73,204	2,762	921,732	36,201	1933		41,217		442,766
1921	30,406	3,450	260,119	22,754	1934	40,544	44,132	214,185	547,353
1922	60,680	4,805	397,729	33,034	1935	37,060	54,547	199,377	677,513
1923	61,355	5,973	376,834	43,184	1936	46,126	75,066	266,883	
1924	55,469	5,541	395,470	47,208					

[1] From compilations by the U. S. Geological Survey and the Bureau of Mines. Data of production for 1927–33 not available.
[2] From compilations by the Bureau of Mines. No imports previous to 1919.

Peat deposits vary considerably in character and as a result the products as placed on the market are variable. The utilization of the deposits of this country has been handicapped not only by lack of adequate information concerning specific uses and results to be expected, but also by the remoteness of deposits from markets and the costs of excavation, drying, and other operations. The imported product is preferable in some cases simply because of its uniformity.

Leafmold has long been a prized organic material, particularly for use with potted plants, but it is difficult to obtain. The product

from oak or beech trees is generally preferred, but the quality is variable, depending upon the kind of trees that produced the leaves, the soil on which the trees were grown, and the extent of leaching and decomposition that has taken place. The freshly fallen leaves pass through several successive stages from surface litter to a well-decomposed humus partially incorporated with mineral soil. Leafmold from deciduous trees is somewhat richer in mineral nutrients, such as phosphorus and potash, than that from conifers. The nitrogen content, which is greatly affected by the proportion of mineral constituents, usually ranges from 0.5 to 2 percent. Lime must be added in some cases if the leafmold is very acid and a more nearly neutral material is desired.

Leaves may be gathered and composted. They are free from weed seeds but in some instances may contain injurious fungi if care is not exercised in their selection.

Woody material, as a source of organic matter, should generally be avoided as it is very difficult to break down into a favorable condition and otherwise has harmful biological effects in the soil. Well-rotted sawdust, however, has in some cases been used satisfactorily.

Straw from cereal crops such as wheat or barley constitutes an annual source of considerable organic matter on farms and is disposed of in various ways. Composts may be made directly or the material may be used as bedding in stables and later composted. Straw is poor in mineral nutrients and is greatly enriched by the absorption and admixture of manure.

Garbage tankage is a product obtained from household wastes in cities and is prepared by treatment of the garbage with steam to render the grease. The residue is dried and ground and for the most part is used locally as a top dressing. This material contains 2 to 3 percent of nitrogen of low availability, but ammonium sulphate is sometimes added to enhance its fertilizer value. Some raw garbage also is fermented by special processes in closed containers.

Many other organic wastes or byproducts have been used or have potential value as soil amendments. Among these may be included winery waste, tobacco stems, cocoa shells, peanut shells, fruit wastes and culls, seaweed, olive pomace, soot or charcoal, cottonseed hulls, and buckwheat hulls. No attempt is made to give a complete list but merely to indicate the variety of available materials.

The various animal or fish byproducts, activated sewage sludge, and other materials with a relatively high content of available nitrogen are considered essentially as fertilizers or as fertilizer ingredients and are dealt with under the general subject of fertilizers.

USES AND EFFECTS OF ORGANIC AMENDMENTS

The structure and other related physical properties of very sandy soils or of heavy clay soils are greatly improved by the incorporation of suitable organic material. In a clay soil porosity is increased and plasticity is reduced, whereas in a loose sandy soil the organic matter has a binding effect and retards excessive percolation.

The organic matter should be finely divided to effect an intimate mixture or a good distribution. In some cases, however, coarse particles may be preferred where blowing or washing of fine particles are

factors to be considered. The proportions of organic matter used to improve the physical properties of soil usually range from 1 part in 5 or 6 of soil up to equal parts by volume. Organic matter is generally incorporated with 2 to 4 inches of the topsoil for lawns and seedbeds, but it may be used at greater depths for trees, shrubbery, or special beds. Top dressings are applied in varying quantities to the surface and gradually worked into the soil.

Surface mulches are frequently used to prevent freezing or the injurious effects of alternate freezing and thawing in winter or early spring, to keep down weed growth, and to preserve soil moisture. A mulch may aid in the absorption of moisture by the underlying soil when the rainfall is high, but it may be disadvantageous under conditions of limited rainfall because it resists wetting after drying out. This is particularly true of peat. Organic matter retards the rate and reduces the depth of freezing and thereby aids in absorption of water by the soil in winter.

When peat is used in liberal quantities it should be supplemented with fertilizers. Peat is deficient in readily available nutrients, since, having been formed in water, it is thoroughly leached. It is also resistant to decomposition, so that whatever nutritive elements it may possess—particularly nitrogen—are liberated very slowly. The addition of relatively small quantities of manure to peat has been reported as giving satisfactory results. In some cases the addition of small quantities of copper, manganese, or iron compounds will prove beneficial.

An acid medium for the growth of acid-loving plants such as rhododendrons, azaleas, kalmia, and similar shrubs may be produced by the use of moss peat or an acid leafmold. An acid soil is also required by most conifers. Acid peats of reaction less than pH 5.5 have been found to prevent, or at least discourage, damping-off of seedlings and other infectious diseases in forest nurseries. Acid materials may also aid in releasing from the soil plant nutrients that would otherwise be unavailable. It has been demonstrated, for example, that rock phosphate composted with peat becomes more soluble. The buffering properties of organic matter may prevent salt injury to plants that sometimes results from a high concentration of fertilizer or other chemicals, and they tend to prevent rapid leaching of bases from a soil of low absorptive capacity.

Moss peat, or acid sedge peat, has been found useful either when used alone or when mixed with equal proportions of sand for the rooting of hardwood and softwood cuttings of certain varieties that are difficult to root in sand. Mixtures of sand and moss peat have been shown, in many cases, to be superior to sand alone for the purpose of hastening of rooting and improving the character of the roots developed. Conditions with respect to the moisture content, aeration, degree of acidity, and other factors must be carefully controlled, however, for optimum results in the particular rooting medium used.

The use of organic matter for preventing or minimizing soil erosion has been studied and is still under investigation at various experiment stations in the United States. Stable manure, green manures, and forest litter are among the materials being studied for their effect on run-off and erosion from field plots.

The use of a very dark organic material on a light-colored soil surface will cause a greater absorption of heat from the sun as a result of the darkened color. The increased warmth may be advantageous where early development or growth is desired, but damage may result in the case of winter mulches when the sheltered vegetation should be kept cool; and under some conditions it is possible that there may also be overheating of tender seedlings.

It is probable that some of the favorable effects from the application of manure, leafmold, or other similar organic materials are due in part to the presence of the rarer or secondary mineral elements. Elements such as manganese, boron, zinc, barium, copper, iron, and others are essential in small quantities, or at least beneficial, to plant growth and may be deficient in the soil or become depleted by continued cropping. Plant tissues ordinarily contain a great variety and relative abundance of the required elements and distinct benefits may result when these are returned to the soil.

The value of organic matter as a means of increasing the moisture supply of the soil to which it is added has frequently been overestimated. Peat or other organic material may possess a water-holding capacity up to 20 or more times that of a mineral soil on a percentage-by-weight basis, and this relationship has led to erroneous conclusions as to the actual amount of moisture that a mixture of peat or other organic material and soil may contain when saturated, as compared to the soil alone. It must be remembered that organic matter has a low weight per unit volume, and comparison of water-holding capacities between organic matter and mineral soil should be based on volume rather than on weight. In general a given volume of peat will absorb only two to three times as much water as an equal volume of soil. Thus, relatively large proportions of organic matter must be incorporated with soil in order to raise the moisture-holding capacity appreciably. Other factors that must be taken into account are the effects of added organic matter on the rate of moisture loss by evaporation, the amount of unavailable water retained by the organic matter as compared with that held by the soil, and the resistance to wetting after having been allowed to become air-dry.

The incorporation of organic matter with a clay soil should not be expected to aid greatly in the retaining of available moisture during a period of drought. It may even be unfavorable from this standpoint. It will serve, however, to render the soil more open and pervious to percolating water. A sand or a very sandy soil, on the other hand, may have its moisture-retaining properties significantly improved by the addition of organic matter.

IN GENERAL, three methods for determining the fertilizer needs of soils are now in use by scientists: (1) The so-called quick tests, made with chemicals, and biological tests, sometimes made with fungi and bacteria; (2) pot and greenhouse tests, involving samples of soil; and (3) plot tests, where the plants are grown under controlled field conditions. Extensive use of quick tests is comparatively new; the plot tests have been used for a long time. This article gives a critical account of all four methods, showing the procedures involved, the results to be expected, and the limitations of each.

Determining the Fertilizer Requirements of Soils

By Oswald Schreiner *and* M. S. Anderson [1]

EVALUATION of the fertility of a soil and of the quantity and quality of fertilizer required for profitable yield and quality of crop is indispensable to economical fertilizer usage and essential to efficient crop production. Three general types of procedures are being used for this evaluation—plot tests with specific crops in the field, pot tests with field crops or selected test crops, and laboratory procedures involving chemical and biological factors.

Since the laboratory tests have been recently popularized and are at present attracting widespread attention, they will be discussed first in this article. Every farmer would like to know whether it is possible, by testing a sample of the soil in a field, to determine just what fertilizer elements are needed for the best economic production of a particular crop, and in what quantities.

LABORATORY MEANS OF DETERMINING FERTILIZER NEEDS OF SOIL

Much attention has been given by chemists and agriculturists to the development of chemical means for the determination of the availability of various mineral constituents in a particular soil. It is, of course, highly desirable to know not only the total or potential supply of a particular element present but also the part of the whole which is capable of serving the immediate and progressive needs of growing plants.

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After many years of intensive research along this line in various parts of the world, the objectives have been only partially accomplished. Experience with growing plants still serves as the main source of information upon which an agriculturist must rely in judging the probable response of plants to particular fertilizer applications upon any kind of soil. Chemical information can be and is a distinct aid, but with the present state of knowledge it must play a supplementary and usually minor part. Valuable use can often be made of chemical data in the diagnosis of the needs of a soil, but if an agriculturist were dependent upon chemical data or any kind of laboratory data alone the results would be very disappointing.

It is a relatively simple matter to make an inventory of the total plant-nutrient resources of a soil by means of an ultimate chemical analysis, but it is well known that no close relationship has been found between the total quantities of various soil constituents and the supply available to plants. Furthermore, the amount of various nutrient elements removed from the soil by water, by plants, or by any one of various extracting solutions bears a very definite relationship to the whole quantity of a particular element present.

In some kinds of soil a fairly good relationship may be found between the total quantities of certain soil constituents and soil fertility. In other cases the composition of the water-soluble material may give a better clue to fertility. In still other cases, perhaps, the chemical data that appear to be best correlated with crop growth and with response of plants to fertilizer applications are most frequently those obtained by the use of some one of a large and varied group of extracting solutions.

The quantity of various elements ordinarily added to a soil in a commercial fertilizer application in any one season is so small as compared with the total normal supply of any one of these elements in the soil, that a chemical analysis for total constituents would ordinarily fail to detect the addition of commercial fertilizer well mixed through the plow depth of soil. Although additions of fertilizer constituents amounting to not more than a few thousandths of 1 percent of the surface soil weight may greatly influence plant growth, they must be detected chemically by their partial solution in selected solvents rather than by their determination in total quantity.

Because of the disappointing results from most of the varied efforts directed at precisely evaluating availability of soil constituents by chemical means, many agriculturists have begun to use approximate tests that are known to be far from perfect.

Anyone interested in rapid soil tests naturally would like to know how accurately these tests may serve as an index of plant growth on the soils tested. Many statements indicating correlation of tests with crop growth in general terms have been published. A few writers have attempted more definite mathematical statements, but for the most part these are not very convincing. Much difficulty is involved in satisfactory correlation because of the varied considerations concerned. Agronomists are interested not only in whether a certain fertilizer does or does not produce a crop increase on a particular soil, but also in whether the increase, if any, is economically advantageous when all factors are considered, as in long-term field experiments.

Extent of Present Usage

Rapid chemical tests in one form or another are used in many of the State agricultural experiment stations as an aid in furnishing advice to farmers regarding fertilizer use and soil management. There is a constantly increasing use in the United States of rapid test methods of estimating the phosphoric acid and potash requirements of soils for the aid of practical agriculturists. So far, however, there is little standardization. The wide variation in soils, climate, character of crops, and other factors makes such soil testing essentially a regional, sectional, or local problem, and the different State experiment stations are sponsoring the development and application of procedures found empirically to yield results correlating best with the results of field plot and other vegetative trials under particular soil and crop conditions.

For routine soil testing, preference is given various forms of the so-called rapid or quick chemical tests that may be conducted with very limited laboratory facilities or in the field. These tests afford approximate quantitative estimations rather than absolute determinations. When standardized against field results and employed intelligently under the conditions for which they were developed, they are reported to be of marked diagnostic value; but great reliability for all crops on all kinds of soils cannot be claimed for any single test.

According to a survey made in 1935 and reported by R. P. Thomas of the Maryland Agricultural Experiment Station (*398*),[2] 26 States, principally in the central-western area, Corn Belt section, and eastern Atlantic region, make extensive use of soil tests for evaluating plant-food requirements. Seventeen other States, mostly South Atlantic and Gulf, as well as Northwestern States east of the Rockies, make limited use of such tests. Only five States are reported as not using such tests in their soil examinations.

Of the tests for plant-food requirements, those for phosphorus find widest application, as deficiency of this element is probably the most widespread of all. Thirty-six States report the use of one or more methods for phosphorus, with largest interest in the Middle Western and Eastern States.[3] No one method was reported as entirely satisfactory for all cases. Various modifications of the sodium acetate extraction procedure seemed to be more widely used than any others—largely in the eastern United States.

Tests for potassium were reported as less extensively used than those for phosphorus or for lime. Only 24 States made such tests and a number of these made them only on request.[4]

This survey showed that at the present time most research workers feel that the rapid tests have been checked under field conditions only

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

[3] Sixteen States, mostly east of Ohio, use some form of extraction with sodium acetate solutions as typified in the Morgan tests, or with dilute acetic acid, as in the Spurway tests. (See table 2, p. 476, for summaries of the tests mentioned.) Twenty-one States, mostly west of Ohio, employ stronger extracting solutions, as represented in the Truog, Bray, and Thornton procedures and their modifications. Thirteen States reported use of the Bray tests, but only 7 exclusively; 13 used the Truog procedure, but only 3 solely. Fourteen States used various modifications of Morgan's tests, eight exclusively. The Spurway tests were used in five States and exclusively in two. The Thornton procedure for phosphorus was used in two States. Four States, Colorado, Montana, Oklahoma, and Texas, reported use of special tests of their own for phosphoric acid, including modifications of other chemical tests, various biological tests, etc.

[4] Eleven States employed Morgan's method, eight exclusively; the Spurway method was used in seve States, but in only three exclusively. Eight States employed the Truog, Bray, and Thornton methods f potash.

to a limited extent and that there needs to be considerable collaboration on the treatment of soil samples and interpretation of the results before a satisfactory comparison of the methods can be made and precision in rapid soil testing attained comparable with field results and practical experience.

Results by Different Methods and Procedures

In view of the extensive use of quick chemical tests by trained and untrained persons, the Department of Agriculture set about to obtain some information regarding comparative results obtainable by various published methods and by the use of various convenient test sets. Some results of this investigation have recently been published in Miscellaneous Publication 259 entitled "Comparison of Various Chemical Quick Tests on Different Soils" (*16*). The results are, as one might expect, inconclusive. Some variations were found in the results by different operators using the same method on one soil, and much poorer agreement was found between results by different methods on certain soils. With some soils all of the methods agreed fairly well; with other soils results were very erratic.

Most students of quick test methods have recognized that different soils respond differently to most soil tests. It is to be expected that the available nutrient constitutents of an acid Red or Yellow soil might respond differently to the action of various solvents than would the corresponding constituents of a nearly neutral Prairie or Chernozem soil. Soils receiving many applications of fertilizers accumulate residues that are transformed into different compounds, depending upon the nature of the soil. Also the purpose for which a test may be made is not always the same. In the case of a lawn, the main object is to obtain a good grass cover; in the case of major field crops, an economic return on a crop of relatively low value is desired; while with truck crops the object of the test is often to find out how to grow vegetables of the finest quality with only secondary emphasis on quantity. Under such varying circumstances it is apparent that several kinds of tests may be useful.

Tests using a dilute solution of a weak acid such as that described by Spurway of the Michigan Station (*382*) and marketed under the name "Simplex Soil Test Outfit" may be of particular value for detecting instances of overfertilization in cases of intensive agriculture. Systems employing relatively strong acid in extracting solutions, one of which is used by the Illinois Station, appear to be of particular value in certain regions. However, when applied to soils having accumulated residues of phosphates from former applications, the apparent values of availability may be relatively much greater than indicated by crop response. The use of mildly acidic, heavily buffered solutions (i. e., not easily changed in reaction one way or the other), such as those employed by the Connecticut Station and others, appears to be growing in popularity, although absolute values obtained by the use of this or any other system are of very limited usefulness without the practical experience of a good agriculturist.

It is difficult to evaluate the usefulness of the various laboratory quick tests as a sole source of information for the guidance of fertilizer practice and for knowledge of the adaptability of crops to the various

kinds of soils. It may appear to some that the statements here given of their practical worth are more conservative than is justified by the experience of several State laboratories. Attention is called, however, to the fact that in these institutions the tests are made and interpreted by agriculturists who have had broad experience with the groups of local soils being tested.

How the Data Are Interpreted

The manner in which chemical soil data are interpreted in terms of crop production is illustrated by reports from several of the State experiment stations. Work at the Texas Station (*114*) led to the conclusion that soils in that State from which 20 to 100 parts per million of phosphoric acid were extracted by 0.2 normal nitric acid usually did not contain enough phosphorus for the proper growth of corn. Potash extracted by the same solvent showed no traceable relationship to weight of crop grown.

The Oklahoma Station (*146*) has issued certain generalizations regarding the relationship of phosphorus extracted with 0.2 normal sulphuric acid and response of crops to phosphorus fertilization. The quantity of phosphorus in Oklahoma soils above which added phosphorus is unprofitable varies with different crops, with approximate limits as follows: 40 to 60 pounds in the soil for alfalfa, 30 to 40 for oats, 20 to 30 for corn, 15 to 20 for grain sorghum.

The Colorado Station (*129*) found water-soluble phosphorus the most reliable index of phosphorus availability in calcareous soils. The phosphorus was determined in a water extract of the soil by treatment with an acid molybdenum solution which, in the presence of reducing agents, gives a blue color when phosphorus is present, the intensity of the color depending on the amount of phosphorus. Positive and negative crop responses only were recorded with no indication as to the extent of crop increase as a result of phosphate application. In spite of the good showing made by the water-soluble phosphate test in this instance, the consensus of opinion from tests made on soils in different regions seems to be that its usefulness is more limited than tests employing certain acid or salt-extraction methods.

Many general statements have been made by investigators concerning the correlation of crop results with those of the popular quick tests, but definite data appear to be few or lacking.

Nature of Rapid Soil Tests

The methods that have been used and those now in use for soil testing are many and widely varied in character. A portion of the equipment in a laboratory where various tests are used and compared is shown in figure 1. Figure 2 shows the operation of one of these test kits. A synopsis is given in table 1 of some of the procedures that are of historical interest as well as some of the methods now in use in various countries of the world and to a limited extent in the United States. A synopsis of methods in common use in the United States at the present time is given in table 2.

It is evident from the information in tables 1 and 2 that the rapid soil tests used in recent years vary widely. Some are quick in the

sense that they require only a few minutes' time, others are biological in character, or in some cases chemical tests are made upon plants grown for stated periods of time in the soils to be tested. The *Aspergillus niger* test, for instance, is purely biological, while the Neubauer method involves actual chemical determination of a single element, either phosphorus or potassium, on seedlings grown under conditions prescribed in the test.

Various State experiment stations have investigated quick tests as applied to the soils of their respective States. Many methods and

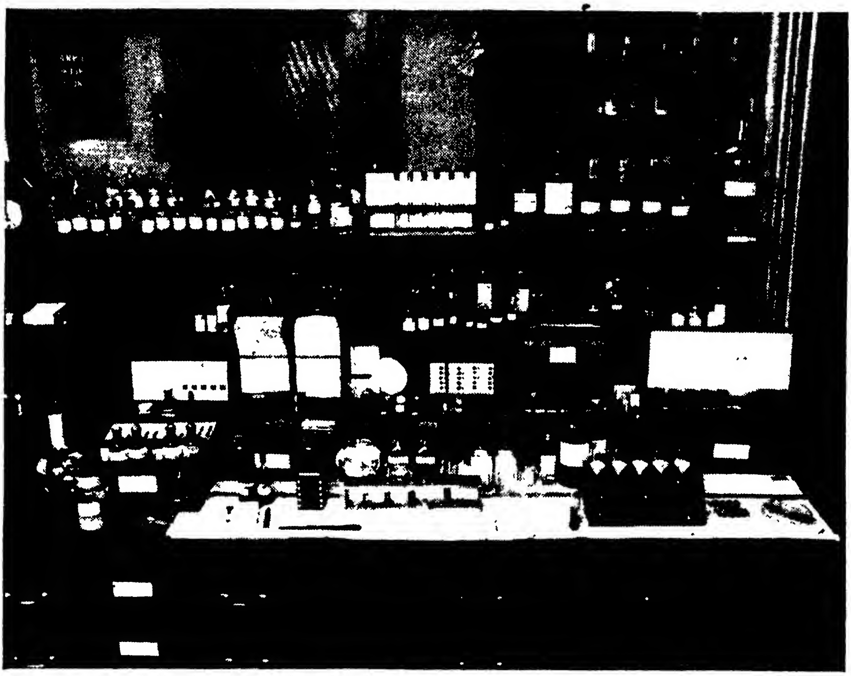

FIGURE 1.—Chemical laboratory showing some of the quick-testing outfits used for evaluating the available nitrogen, phosphorus, potassium, and other elements contributing to crop productiveness. Laboratory results aid experienced agronomists in determining soil fertility and specific deficiencies and in recommending suitable fertilizer materials or other soil-improving processes.

modifications of methods have been published by these institutions. In several cases the methods have been commercialized. Several of the firms selling testing sets, however, give no indication as to the chemical composition of the reagents used in their various tests, expecting to furnish refills when needed.

The chemical methods, including the nature of the extracting solution, vary in respect to acidity and other characteristics.[5] Some

[5] Some procedures employ a single extracting solution for dissolving the various constituents to be determined. M. F. Morgan, of the Connecticut Station, and J. B. Hester, of the Virginia Truck Station, each follow this plan. The solution used by Morgan is made as follows: 100 grams of sodium acetate crystals are dissolved in 500 cubic centimeters of water, 30 cubic centimeters of glacial acetic acid is added, and the whole is made up to 1 liter. This mixture of salt and acid is strongly buffered at the mild acidity value of pH 4.8. The solution used by Hester is made by adding 20 cubic centimeters of glacial acetic acid and 10 grams of sodium hydroxide to sufficient water to make a volume of 2 liters. The extracting solutions used for individual constituents are numerous and varied; many of them are more acid than those noted above.

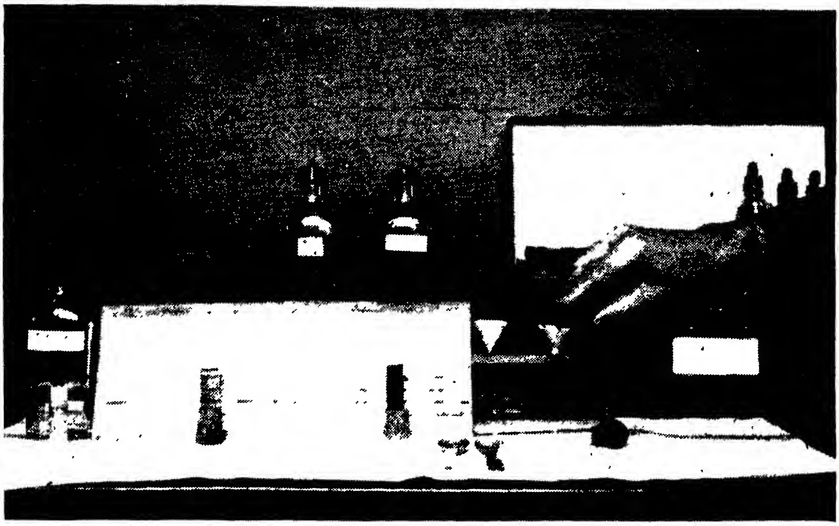

FIGURE 2.- One of the soil-testing outfits used for phosphorus and potash. On right is shown a step in the preparation and filtration of the test solution. At left is shown color comparison against a standard color chart for phosphate. In center is shown a turbidity test for potash, in which the intensity of the black lines visible through the turbid solution is compared on a standard chart.

Table 1.—*Rapid methods of soil testing developed in different parts of the world*

Author and reference [1]	Year and place originated	Extracting reagent	Remarks
Daubeny (*90*)	1845, England	Carbonic acid	
Von Liebig (*217*)	1872, Germany	Dilute hydrochloric or acetic acid.	Potassium and phosphorus are both considered.
Lechartier (*213*)	1884, France	2-percent ammonium oxalate.	For phosphorus only.
Dyer (*98*)	1894, England	1-percent citric acid	Soils with less than 0.01 percent soluble phosphoric acid (P_2O_5) probably need phosphatic fertilization.
Association of Official Agricultural Chemists (*465*).	1907, United States	0.2 normal hydrochloric acid.	For phosphorus only.
Neubauer and Schneider (*278*).	1923, Germany	Analysis of seedlings grown in soil.	A single test may be for either phosphorus or potassium.
Das (*89*)	1926, India	Alkaline carbonate solutions.	For calcareous soils potassium and sodium carbonates better than ammonium carbonate.
Hoffer (*167*)	1926, Indiana		Various reagents used on cornstalks indicate deficiencies of nitrogen, phosphorus, and potassium.
Oden (*284*)	1927, Sweden	Electrodialysis	
Murphy (*274*)	1934, Oklahoma	Conventional base exchange procedure.	
Mitscherlich (*268*)	1924, Germany		Test plants are grown in pots.

[1] To Literature Cited, p. 1181.

Table 2.—*Rapid chemical tests for phosphorus and potassium in soils, commonly used in the United States*

PHOSPHORUS TESTS

Author and reference [1]	Agricultural experiment station where originated	Extracting reagent	Method of estimating element
Morgan (*270*)	Connecticut	Sodium acetate+acetic acid; 5 normal, pH 4.8.	Sodium molybdate+stannous oxalate.
Spurway (*382*)	Michigan	Dilute acetic acid; about pH 3.2.	Ammonium molybdate+tin.
Truog (*417, 420*)	Wisconsin	0.002 normal sulphuric acid buffered at pH 3.0 with ammonium sulphate.	Ammonium molybdate+stannous chloride with precautions to eliminate effects of arsenic and silicon.
Bray (*44*)	Illinois	Ammonium molybdate in 0.1 normal hydrochloric acid solution.	Add tin.
Thornton (*404*)	Indiana	Ammonium molybdate in 0.1 normal hydrochloric acid solution.	Stannous chloride or stannous oxalate.
Fraps (*114*)	Texas	0.2 normal nitric acid	Gravimetric or volumetric molybdate method.
Fraps (*115*)	do	do	Colorimetric molybdate method.
Hester (*160*)	Virginia Truck	Sodium acetate+acetic acid; 0.167 normal (acetate) pH 5.0.	Do.
Harper (*146*)	Oklahoma	0.2 normal sulphuric acid.	
Hance (*140*)	Hawaiian Sugar Planters Association.	0.5 normal hydrochloric acid.	

POTASSIUM TESTS

Author and reference [1]	Agricultural experiment station where originated	Extracting reagent	Method of estimating element
Morgan (*270*)	Connecticut	Sodium acetate+acetic acid; 5 normal, pH 4.8.	Sodium cobaltinitrite+isopropyl alcohol.
Spurway (*382*)	Michigan	Dilute acetic acid; 1:3	Sodium cobaltinitrite+alcohol.
Thornton (*404*)	Indiana	Sodium cobaltinitrite in acetic acid.	Add alcohol.
Bray (*44*)	Illinois	Sodium acetate+nitric acid.	

[1] To Literature Cited, p. 1181.

consist of acids well buffered with salts. The ratio of soil to extracting solution varies, as does also the time of contact. In most cases a measured volume of an extracting solution is shaken with a definite volume of soil for a specified short period, then the mixture is either allowed to settle or is filtered.

Different soils, of course, form water extracts which vary widely in the rate at which liquid passes through the filter; thus the period of contact of soil with extracting solution is unavoidably varied. Methods employed for quick tests in various institutions and materials furnished with some of the commercial outfits change frequently. Outfits sold a few months ago may not be identical with those currently offered for sale, and the methods of institutional workers may likewise be amended through revised bulletins on the subject.

Chemical Reactions Involved in Tests

Probably all of the chemical rapid tests for phosphorus utilize some modification of the Deniges method for determining minute quantities of phosphates. According to this method a blue color is developed when soluble soil phosphate in an acid molybdate solution is treated with a stannous salt or stirred with metallic tin. A definitely per-

ceptible blue color is obtained with solutions containing as little as 0.1 part per million of phosphorus.

Potash is determined in most, but not all, of the chemical procedures by precipitating with sodium cobaltinitrite in the presence of ethyl alcohol or isopropyl alcohol. The turbidity produced is then estimated in some prescribed manner. For example, in several cases the soil solution together with the reagents, amounting to a definite volume of perhaps 2 cubic centimeters, is placed in flat-bottom glass tubes of uniform diameter. These tubes are moved over a series of colored lines of varying clearness of definition against a white background (fig. 2). The line which is first visible through the turbid solution corresponds with the supply of available potash designated as high, low, medium, or by similar designations. The potash turbidity method as ordinarily used is somewhat less sensitive than the phosphorus color test. About 5 parts per million of potassium in solution usually represents approximately the minimum detectable turbidity.

The determination of available nitrogen is complicated by the fact that organic compounds, many of which are of low water solubility, are slowly ammonified and nitrified in the soil during a growing season. Thus a supply of readily soluble and available forms of nitrogen is considered as being produced at a rate more or less comparable to the rate of their absorption by plants. If not taken up by plants, the excess may be lost in drainage water. Hence, the quantity of nitrates present at any one time is seldom high in soils of humid regions, and furthermore is a poor index of the capacity of a particular soil to produce a sufficient available supply regularly.

Most of the soil-testing systems include a procedure for determining nitrates, and they ordinarily use the same reagents. Small quantities of soil solution are treated with diphenylamine and concentrated sulphuric acid. A blue color develops, which is compared with a color chart the tints of which correspond to definite quantities of nitrate. A definitely blue coloration is detectable when quantities as small as 0.3 part per million of nitrate nitrogen are present. Ammonium nitrogen is frequently determined by the production of a yellowish-brown coloration with the well-known Nessler's reagent. This reagent is a complex one, but consists essentially of a strongly alkaline solution of mercuric iodide. This solution has long been used as a standard reagent for the detection and estimation of minute quantities of ammonia, particularly in sanitary water analysis. The color of an unknown solution is compared with a color produced in a solution of known strength or with a standard color chart. Organic nitrogen is sometimes determined by the use of some oxidizing agent, which produces either some direct color change or ammonia, which is then determined as above.

Tests for Calcium, Magnesium, and Other Soil Constituents

In addition to the ordinary fertilizer constituents—phosphorus, potassium, and nitrogen—other elements are often included in the more complete systems of chemical soil testing. Systems such as those de-

scribed by Morgan and Spurway (*270, 382*) include tests for these. In making a diagnosis of soil conditions it is sometimes important to know the relative concentrations of such constituents as calcium, magnesium, aluminum, manganese, and sodium, as well as chlorine and sulphur. Soils are frequently deficient in some one or more of these, and frequently excessive quantities of certain of these elements present a problem. The coincidence of the various constituents is in many cases perhaps of even more importance in soil diagnosis than is the concentration of any one element alone. In the case of these less commonly considered constituents information is so scant regarding the normal concentrations found in soil extracts that much comparative work is usually necessary in a particular locality before it can be ascertained whether or not it is practical to attempt soil adjustments on the basis of such chemical information.

In addition to the constituents mentioned, certain trace elements such as copper, boron, and zinc are known to be of normal occurrence in soils, and the available supply of one or more of these appears sometimes to be inadequate. Little is known regarding the normal limits of any of these trace elements or of suitable laboratory methods for testing for them in an adequate manner. Here, as with the fertilizer elements, the response of plants is a more positive guide than are chemical tests.

Methods of Expressing Results

Rapid chemical soil tests should be looked upon as having good qualitative or semiquantitative accuracy. The modes of expressing results are not uniform. Some express results as parts per million of a particular constituent in available form in the soil. Others interpret them directly from color comparisons in terms of probable applications of a particular element needed for good crop growth. The available supply of a particular constituent is often indicated only in general terms, such as high, medium, low. In still other cases a general expression of results is further broken down into five groups by adding the additional classes "very low" and "very high." By the exercise of some judgment on the part of the operator not contemplated by the author of certain methods, results from any one of the procedures may be interpreted as falling into one of the five groups just mentioned. It is doubtful whether the accuracy of the results or their susceptibility to practical interpretation ordinarily justifies more detailed expression than is possible in these five groups.

BIOLOGICAL METHODS

Several biological methods have received considerable attention in this country as well as in Europe. Some of them involve the growth of ordinary field crop plants under specified conditions in a greenhouse; other procedures utilize the growth of lower forms of plants, such as fungi and bacteria, to detect differences in soil fertility.

The Mitscherlich method (*268*), widely used in Europe, has been tried in a few laboratories in this country. It consists of growing selected test crops under controlled conditions in specially constructed pots. This method involves considerable expense for equipment and considerable time in operation. Experience alone must be relied upon

to determine whether or not the results obtained, using a particular test crop on a particular soil, provide a reliable growth index for other crops whose nutrient requirements are different.

The Neubauer procedure (*278*), also of European origin, has been used by various investigators in this country. The method, in brief, consists of growing a definite number of seedlings of some test plant, often rye, in a definite weight of soil in a shallow dish. Moisture conditions are kept at an optimum and all elements supplied in optimum amount except the one being tested. Either phosphorus or potassium deficiencies may be determined, but the method is not applicable to nitrogen. After a definite period of growth the plants are analyzed for either phosphorus or potassium. Experience is necessary to determine the probable border line between sufficiency and deficiency of an element in a soil as revealed by the seedling composition. Owing to the time involved in the conduct of such tests and the indefinite character of the results obtained, they have not been widely used in the United States.

Other biological tests of an indirect character include the growth of cultures of *Azotobacter*, *Aspergillus niger*, or *Cunninghamella* organisms. Unpublished data obtained in the Division of Soil Mircobiology of this Department convinced the investigators that such methods lack practicability. Much experimentation is involved in standardizing these tests so as to make the growth data capable of interpretation in terms of the fertilizer needs of various crops on different kinds of soil.

POT AND GREENHOUSE METHODS FOR DETERMINING FERTILIZER NEEDS OF SOIL

Pot experiments, particularly with rapidly growing indicator crops, permit tests with a large number of soil treatments within limited space and in relatively short time. The results are often directly applicable in practice, although allowance must be made for the fact that the conditions of the test are different from those in the field—the soil has been disturbed, and the more uniformly controlled temperature, moisture, and other factors modify the influence of the soil treatments themselves. In supplying information on the fundamental fertility characteristics of soils and particularly on the effects of specific substances on plant growth, pot experiments have the advantage of being less influenced by variable environmental factors than are field trials. The pot tests with soil, sand, or solution culture are most valuable in the study of certain specific factors such as the relative value of different forms of nitrogen, the toxicity of certain constituents and the variable absorption of particular elements by plants. Figure 3 shows a system of pot tests in a greenhouse.

Pot tests have long been in use. Sometimes they are conducted out of doors but most frequently in a greenhouse where conditions are more definitely under control. In some cases the technique is simple, in others special techniques, including special types of containers, are developed for the solution of particular fertility problems.

In the simplest form of experiment, earthenware pots of 1 to 5 gallons' capacity, frequently provided with a drainage vent near the bottom, are filled with the soil to be tested. Since soils are severely

disturbed by transfer from the field to a pot there is usually no attempt made to simulate the naturally successive soil layers.

Testing Fertilizers or Amendments

The uniform incorporation of various ingredients with soil presents considerable difficulty. A heavy application of fertilizer, corresponding to 1 ton per acre, would require only about one-third of an ounce for treatment of a 2-gallon pot containing about 20 pounds of soil. Uniform distribution is most easily accomplished by mixing the contents of each pot separately in a small mixing machine. If some treatment requires only minute quantities of a constituent, such as are used when effects of such elements as zinc, copper, or manganese

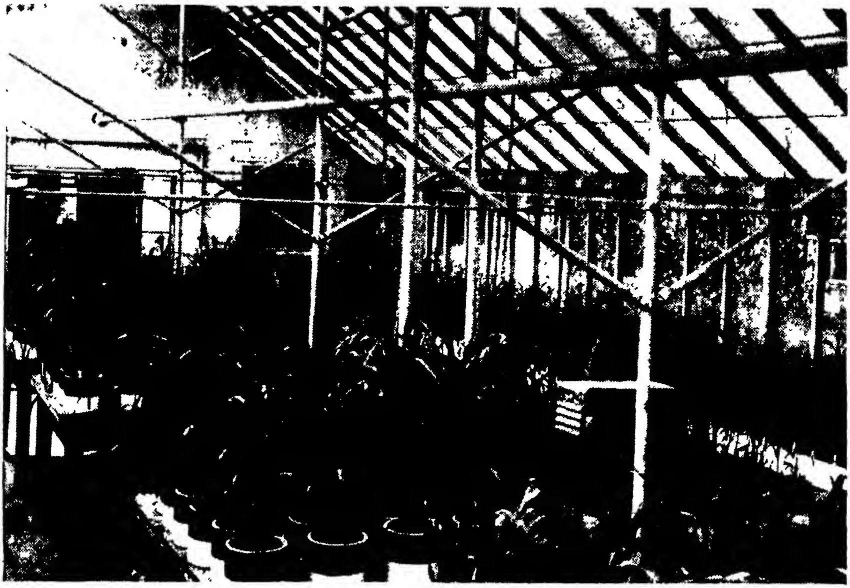

Figure 3.—Greenhouse tests are made with soils and fertilizer materials under controlled conditions, using many crop plants, in pots, for the study of fundamental problems of soil fertility and plant nutrition.

are being investigated, the material may be dissolved in water and a definite volume sprinkled over the mass of soil previous to mixing.

The soil is in each case added to the pot with some arbitrary but uniform method of compacting. Frequently the pot is half filled, then lightly tamped with an appropriate implement. Seed are sometimes planted in the soil and the weaker seedlings removed to leave a uniform number fairly evenly distributed over the soil surface. In other cases, seeds are sprouted in a moist chamber and a definite number placed in each pot.

It is important that light, heat, and moisture conditions be kept as nearly uniform as possible throughout the growing period of the plants. Plants are grown to varying degrees of maturity. Sometimes they are harvested after a specific period of time and the weight of the

whole plant, green or dry, is taken as a basis for comparison. In other cases, plants are grown to maturity and comparison made on the basis of weight of fruit or seed or dry weight of total growth. Figure 4 shows such an experiment in progress with several different crops. The sunken tiles and surrounding gravel when kept wet prevent excessive temperature and moisture fluctuations in outdoor experiments.

New fertilizer materials are frequently best tested out under such controlled conditions. In this work the new material is added to definite amounts of soil in pots and the relative growth obtained is observed and recorded. The untreated soil serves frequently as a

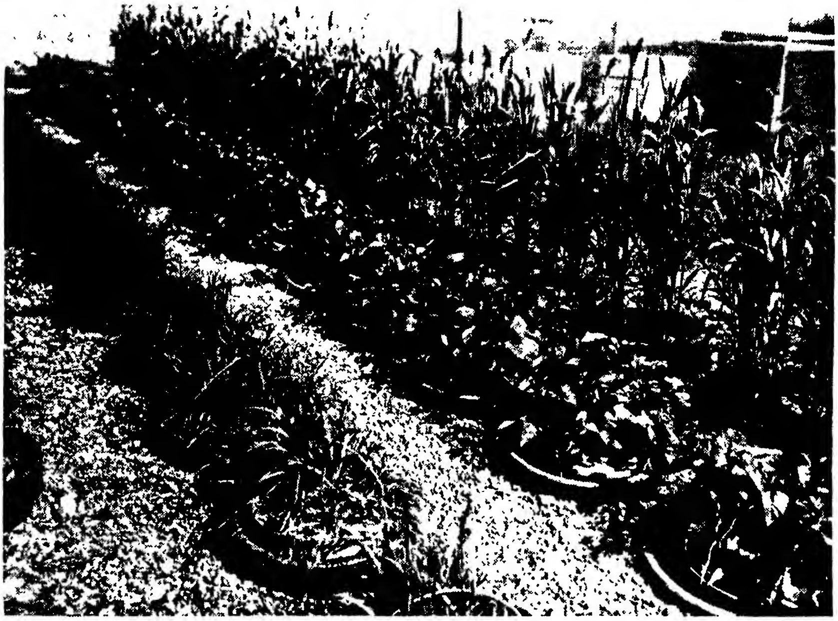

FIGURE 4.—Pot tests made under outdoor conditions in wire-netting enclosures, with the pots inserted in submerged tiling to control temperature and moisture, are often used in soil and fertilizer studies.

comparison, or soil treated with some standard fertilizer material of known efficiency may be used.

A recent experiment of this kind by the Department was a comparison of a new synthetic organic nitrogen compound known as formamide, proposed as a potentially cheaper nitrogen carrier, with more commonly used nitrogenous compounds such as ammonium sulphate and urea. By pot experiments in which oats, wheat, and millet were used as test plants, it was shown that this new source of nitrogen compared favorably with the standard compounds. Such preliminary tests justify more elaborate and expensive field tests to evaluate the economic worth of formamide. Pot tests of this kind are extensively used in the nitrogen industry, to eliminate unfavorable nitrogen

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carriers from further consideration. Similarly, various phosphate and potash compounds can be evaluated.

In fertilizer testing in the greenhouse, especially in studying the relative fertility of different soil types, larger containers are frequently necessary. Greenhouse benches that provide an area 4 feet square for each soil type or treatment provide conditions under which crops can readily be grown to maturity.

Pot tests are especially valuable in the determination of deficiencies of certain minor elements, such as iron, manganese, zinc, boron, or others. An experiment in this Department with a mysteriously unproductive soil showed through pot tests that the difficulty was due to manganese deficiency. A few milligrams of a soluble manganese compound added to the soil in a pot produced normal plant growth and fruit in a tomato plant, while a similar plant in the original soil without the manganese showed chlorosis and bleaching of the leaves and died without producing flower or fruit. Subsequent experimentation on a field scale confirmed the indications of the pot test, and large areas of this unproductive soil were made available for profitable truck farming by the application of the deficient element. Numerous other illustrations might be chosen from the experiment station literature to show the value to agriculture of the pot method of experimentation.

FIELD EXPERIMENTS FOR DETERMINING FERTILIZER NEEDS OF SOIL

For evaluation of fundamental soil fertility factors and specific soil properties affecting the level and proportions of available plant nutrients, the pot cultures and laboratory procedures are highly advantageous, since environmental influences modifying the effects of the strictly soil factors, as measured by crop growth and yields, are minimized and controlled. But for direct evaluation of fertilizer requirements, taking into account all factors affecting crop production, field trials remain the ultimate criteria. Field experiments are, however, relatively slow and expensive, particularly as regards labor and area of land required and the necessity for replication of treatments and for averaging seasonal fluctuations over a period of years.

In field trials, different fertilizers and other cultural treatments are tested with various crops under essentially the same conditions as prevail in practice. The results reflect the effects of all climatic and other influences to which the crop and soil are subject during the season. They are directly indicative of the results to be anticipated in practice under the same or similar conditions.

A typical lay-out for this work requires a considerable area of fairly uniform land. The contour should be such that none or very little of the surface run-off from precipitation passes from one plot to another. The plots of different experimental fields vary in size. Frequently about one-twentieth of an acre is used for each treatment. Check plots are interspersed with plots receiving definite fertilizer treatments and specified crop rotations. Numerous replications (*341*) are required for accurate results and to make possible statistical handling to determine experimental errors and smooth out irregularities. In the eastern Coastal Plains region emphasis is necessarily placed upon

kind and quantity of fertilizer added while on prairie soils the plan of crop rotation is often the subject of most profitable study by this system.

Crops adapted to the region are planted on the various plots and are given uniform tillage treatments according to what appears to be the best practice of the region. At the proper season, the crop of each plot is harvested separately and weighed or measured under the direction of a competent agriculturist.

Several important lines of information are obtained from this class of experiments. By reference to the check plots it is determined whether or not crop improvement, in quantity or quality, has taken place as a result of any particular soil or fertilizer treatment. The most valuable results are obtained only after a period of years when it is possible to determine from average yields and from the changing trends of yields what treatments give greatest response.

The economic aspect of the work can also be evaluated from the cost of fertilizers and value of crops each season. These are features which only a carefully considered series of field-plot tests can show, since these more nearly simulate farm operations and conditions than do pot tests or any of the chemical or biological tests previously described.

Farmers as a class are conservative. They do not undertake important changes in methods of farming without good reasons. While most farmers have faith in the programs of their State experiment stations, this faith becomes conviction when they can go and see crops of markedly different size and vigor growing side by side as a result of different treatments or rotations. This work of the stations is an important factor in improving local farm practices. For instance, through it a farmer is often influenced to try some treatment or other on a strip of his own field. Thus the experiment is expanded from the part-acre plot basis to open field trials of many acres. Farmers who do not visit the formal experimental plots are often in contact with someone who has; others read the station bulletins where the results from the plots are described in detail. Almost every local paper contains reviews of statements given out by the agricultural extension service of the State. These are often founded upon the results of the field-plot tests which have later been extended to greater acreage.

SOME RESULTS OF LONG-TERM SOIL-FERTILITY EXPERIMENTS

Special mention should perhaps be made here of long-term experiments in the United States that were inaugurated in the earlier periods of fertilizer experimentation at the Illinois, Pennsylvania, and Ohio Agricultural Experiment Stations. The type of information that can be issued by a station after such long-continued plot experimentation is illustrated by the results of some of these older stations.

The Morrow plots at the Illinois Station (fig. 5), begun in 1879 by George E. Morrow, are the oldest existing soil experimental plots in the United States. The series originally contained seven plots, on part of which use was made of fertilizers and manure. Three of the original plots still remain; the others have been used for building purposes in the development of the University of Illinois. Other experi-

mental plot work in Illinois was begun in 1902 on the North Farm and in 1903 on the South Farm of the experiment station, by Cyril G. Hopkins, and these plots are still under observation. On one of the Morrow plots, corn has been grown continuously; on a second plot a rotation of corn and oats has been practiced for the entire period; and on the third, corn, oats, and clover have been grown in rotation since 1902 (*91*). Results from these three plots are briefly as follows:

Crop rotation has noticeably improved the yields over continuous corn growing.

Clover has been of much benefit in the cropping system.

On the untreated land, crop yields have steadily declined.

Cropping the land without treatment has used up phosphorus, nitrogen, and other elements, and has resulted in the destruction of organic matter.

Manure-limestone-phosphate treatment has converted a downward trend in yield into an upward trend.

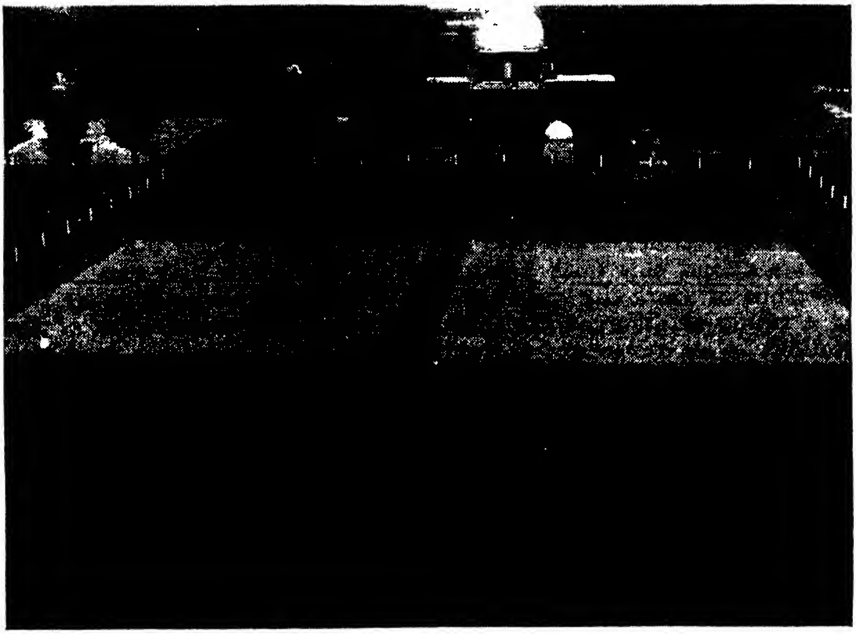

FIGURE 5.—The Morrow plots of the Illinois Agricultural Experiment Station, in operation for more than 60 years, are the oldest experimental plots in the United States. "They stand as a monument, marking the tragedy of soil exhaustion"—but "tell also the story of Nature's eternal persistence in maintaining production where man has carried his share of the responsibility in providing suitable soil conditions" (*91*). (Courtesy Illinois Station.)

The oldest extensive plot tests of fertilizers are those by the Pennsylvania Agricultural Experiment Station, laid out in 1881 by W. H. Jordan. Four tiers of thirty-six plots, each one-eighth of an acre in size, are used for the growing of corn, oats, wheat, and mixed clover and timothy in rotation on Hagerstown clay loam, a prominent soil of the district. The objects were to test the comparative effects of the following treatments on the crops grown: Single fertilizer ingredients; combinations of two ingredients; complete fertilizers; nitrogen in different forms and amounts; superphosphate and ground

bone; manure in different amounts in comparison with commercial fertilizers; burnt lime and ground limestone used alone, and burnt lime used with manure; and land plaster. Jordan applied nitrogen, phosphoric acid, and potash at the rates of 24, 48, and 100 pounds per acre, respectively, as the standard treatment every second year; and on the corn and wheat crop different rates of nitrogen, namely 24, 48, and 72 pounds per acre, were applied in alternate years, using three different forms of nitrogen—dried blood, sodium nitrate, and ammonium sulphate.

After 40 and 50 years of continuous experimentation on the Jordan plots, conclusions issued by the station state that phosphorus is a limiting element of first importance in this Hagerstown loam soil. When used alone or in any fertilizer combination it resulted in substantial increase of crop yield. Potash alone gave only a slight increase, but when added with phosphorus the increase was greater than with phosphorus alone.

Investigational plot work on fertilizers was begun at the Ohio Agricultural Experiment Station in 1893 by Charles E. Thorne, growing corn, oats, wheat, clover, and timothy in rotation, with applications of nitrogen, phosphoric acid, and potash, singly and in combination. With these tests at Wooster and a number of other points in the State, Ohio has probably the most extensive outlay of plots in the United States. Another important older series of experimental plots is that of the Missouri Agricultural Experiment Station.

There should also be mentioned the long-term cylinder experiments of the New Jersey Station begun in 1898 and continued to this day by J. G. Lipman and A. W. Blair. Corn, oats, wheat, and timothy were grown in rotation in 60 cylinders, each 4 feet deep and 23½ inches in diameter, open at both ends and set into the soil to simulate natural drainage as much as possible. The availability of nitrogen from different sources being the main object of the experiments, manures, dried blood, sodium nitrate, and ammonium sulphate were used in various combinations.

Twenty years of plot experimentation on Barnes silt loam at the South Dakota Station led to the definite conclusion that on this soil phosphorus was the one element notably deficient and that its use as a fertilizer was economically profitable.

At the Iowa Station emphasis has been placed upon crop rotation. Rotations of 4 or 5 years have been shown to be of more value than a shorter 3-year rotation. Barnyard manure has played an important part in the treatment of these plots. The best amounts to apply to this Carrington loam soil are between 8 and 16 tons per acre.

It is not feasible here to review further the results of the work at the various State experiment stations. These have been considered by the respective States, and in most cases public reports have been issued covering the crop yields and interpretations of their meaning for practical agriculture. It is desirable, however, to call attention to the local information obtained by long-time field experiments. There appears to be no other way of accurately evaluating the influence of various farm practices upon crop yields.

Field tests have been the longest and most widely used of any form of soil experimentation, and they remain the most reliable means of

determining directly the fertilizer requirements of a given crop on a given soil. They are the only means of studying the varying crop-producing power of soils in place, with the subsoil undisturbed, and with the crop plants subject to the climatic and other environmental influences that frequently materially modify the effects of the soil-fertility factors.

The results of field tests reflect all these influences and are indicative of the results to be anticipated in practice under the same conditions.

Valuable as field-plot experimentation is to the advancement of agriculture, the plot testing system cannot escape criticism entirely. Some of its shortcomings should be recognized. Agricultural practice is slowly undergoing changes on several fronts. Plans initiated 50 or even 25 years ago may in some ways be impractical today. A continuous-crop plot probably contributed valuable information for a period of years, but now the disadvantages of continuous cropping as a general practice are so well known that it hardly needs further emphasis.

Early experiments frequently called for particular fertilizer ingredients which have since been supplanted by cheaper products as good or better. To make a change breaks the continuity of the experiments and thus eliminates one element of their distinctive value. Then, too, some of the older plots were laid out in fields which have since been shown to consist of more than one soil type. In other cases, the soils have been shown to lack the typical qualities of any one soil series, or to be laid out on a soil type of only limited extent. Another feature not always properly safeguarded is the possibility of outwash from one treated plot onto another.

In spite of certain moderate criticisms that may be directed at long-time field-plot experiments, there is no doubt that they have contributed much toward the improvement of agricultural practice in our country. Some modifications may be needed from time to time, but the results warrant their continuation.

For these reasons the State experiment stations and the Department also have been conducting soil and fertilizer studies on farms selected for this purpose, conducting the experiments cooperatively with the farmers under the supervision of competent agriculturists. The county agents cooperate in most of these practical tests on the farmers' own land. Much of the value of such experiments lies in their continuance over a period of years, and their repetition in many localities, thus giving a broader cross section of soil and fertilizer behavior over large areas of soil types or crop regions. This type of scientific testing brings the results closest to the farmer's local problems and needs.

THIS ARTICLE begins with a brief survey of the effect of the World War in stimulating the fertilizer industry in the United States, and then outlines the situation today. First the sources of nitrogen, phosphorus, potassium, and some elements not commonly used in fertilizers are broadly discussed. Then certain effects of fertilizer materials are considered. A detailed appendix, arranged for ready reference, describes the commercial materials now available and their uses, together with some materials still in the experimental stage.

Fertilizer Materials

By Oswald Schreiner, Albert R. Merz, and B. E. Brown [1]

THE use of fertilizer materials as a means of supplementing the natural food supplies of the soil is of considerable importance among the various factors involved in the economical production of crops as well as in the proper maintenance of soil fertility. Without certain elements, such as nitrogen, phosphorus, potassium, calcium, magnesium, and some others, plants cannot live. With inadequate amounts of these elements plants are undernourished and fail to grow and produce normally. Undernourished plants, in turn, are likely to mean undernourished men and animals. It is to supply deficiencies in these essential elements that fertilizer materials must be added to the soil.[2]

Because fertilizer materials increase the production and improve the quality of crops, they have become an essential element in farming in all countries practicing modern agricultural methods. It is probably true that there has never been a greater need than now of aiding farmers to secure maximum returns from fertilizer materials. They represent a considerable share of crop-production costs and should therefore be bought and used with care. The farmers of the United States spend annually a sum in excess of $200,000,000 for fertilizers.

[1] Oswald Schreiner is Principal Biochemist, Division of Soil Fertility Investigations, Bureau of Plant Industry; Albert R. Merz is Chemist, Fertilizer Research Division, Bureau of Chemistry and Soils; and B. E. Brown is Senior Biochemist, Division of Soil Fertility Investigations, Bureau of Plant Industry.

[2] It should be emphasized at this point that the use of fertilizer materials or fertilizer mixtures is only one of a number of means for maintaining soil fertility and crop production at a high level. Proper drainage, maintenance of soil organic matter, prevention of soil erosion, proper care and use of manure, improvement of the physical condition of the soil if this is essential, and liming when indicated, are all necessary to productive farming. Combined with these should be good cultural care and close observation of the crops grown. The greatest benefit from the use of fertilizer materials results when these other controllable factors are taken care of. On poorly drained acid soils that are lacking in organic matter or on soils very leachy in character, fertilizer materials cannot be expected to give a good account of themselves. With improved drainage conditions, the proper amount of lime to control soil acidity, and the addition of some form of organic matter to the soil, a much better response to fertilizers may be expected. Until the controllable factors are properly taken care of, the indiscriminate use of fertilizer materials may be considered to be more or less of a gamble.

Fertilizer materials not only possess great agricultural value for crop production (fig. 1), but they are of importance in domestic and foreign trade. As civilization becomes more complex, so do food requirements and standards, and as population increases, the demands on the soil increase also. In the future it will be necessary to guard the soil and its products from deterioration more carefully than ever. To produce the right quantity of foodstuffs of the right quality will increasingly tax the energies of scientists and farmers alike in the years to come.

INFLUENCE OF WORLD WAR ON FERTILIZER MATERIALS

The influence of the World War on the production of new fertilizer materials was very marked. The insistent demand for propellent powders, high explosives, and other death-dealing materials, chemical

FIGURE 1.—Approximately 50 percent of the total consumption of fertilizer materials in the United States is accounted for by the cotton crop. Some idea of the response of cotton to a proper combination of fertilizer materials is shown by these piles of seed cotton from two 1/20-acre experimental plots. The pile on the left is from unfertilized land; that on the right from fertilized.

in nature, was so great that huge chemical plants were erected to meet the requirements.

The chief concern of all belligerents, insofar as explosives was concerned, was to have a plentiful supply of nitrogen. Those who were cut off from natural supplies of fixed nitrogen, such as Chilean sodium nitrate, had recourse to the greatest source of nitrogen—the atmosphere. The situation from a chemical point of view was a difficult one. First of all, nitrogen is one of the most inert of all the known elements with respect to entering into combination with other elements to form stable compounds. Under ordinary conditions it refuses to react with other elements. Thus special conditions for such reactions had to be provided. Separation of nitrogen from the other gases in the atmosphere proved to be the first requirement. Then through controlled chemical processes it was made to react with other elements, a process generally known as nitrogen fixation. The final step was the production of stable compounds.

In Germany, inability to obtain sodium nitrate from Chile had been anticipated in advance, and the development of economically successful methods of nitrogen fixation had been accomplished before hostilities got under way, so that Germany was independent of outside supplies

of combined nitrogen. This utilization of atmospheric nitrogen as a raw material so impressed certain of the Allies that steps were taken to install plants capable of extracting and fixing atmospheric nitrogen. The United States, for example, is now in a position to protect itself adequately in this respect, agriculturally and otherwise.

When the World War terminated, the huge chemical plants, geared to capacity production of wartime necessities, faced a difficult situation. In order to avoid ruin, these plants turned to the manufacture of nitrogen and other compounds for fertilizer use. It was not long before many new compounds were being produced. Some of these contained nitrogen alone, others nitrogen and phosphorus, others nitrogen and potassium; and in some cases compounds were produced containing all three fertilizer elements.

Two lists of fertilizer materials, one showing materials available about 1900, the other those in use or proposed for use in 1936, are given in tables 1 and 2 (*48*).[3] These two lists typify the marked changes that have taken place during this period, a great many of which resulted directly from the World War.

In comparing the two lists one is impressed with the fact that most of the changes during this transitional period have been confined largely to the nitrogen and phosphorus columns. Another point worthy of notice concerns the high plant-food or nutrient content of some of the materials in the 1936 list. Two materials serving to illustrate this are (1) urea, with a content of practically 46 percent of nitrogen, and (2) diammonium phosphate, which contains 21 percent of nitrogen and 53 percent of phosphoric acid (P_2O_5), a total of 74 percent. The development of urea, a highly concentrated nitrogen material, from more or less of a laboratory curiosity to its present commercial importance as a fertilizer material is an excellent illustration of what chemical research means to agriculture.

Fertilizer materials available for fertilizer use in 1900 present a decided contrast to urea and diammonium phosphate. Aside from the two high-grade potash salts, potassium chloride and potassium sulphate, no such plant-food concentration was found in fertilizer materials then. Among nitrogen materials at that time, ammonium sulphate ran highest in nitrogen content—about 20 percent nitrogen. Sodium nitrate contained about 15.5 percent of nitrogen. In the phosphoric acid group, ordinary superphosphate was practically the main source of phosphoric acid for fertilizer use. For many years it was designated "16 percent super" and only in comparatively recent years have 18- and 20-percent superphosphate materials been produced. The modern trend has been one of providing fertilizer materials with greater plant-food concentration as a means of effecting economies in the manufacture, handling, and transportation of fertilizers.

Other materials proposed for fertilizer use today but not appearing in this list include ammonium formate, formamide, melamine nitrate, melamine phosphate, melamine sulphate, guanidine sulphate, diguanidine phosphate, triguanidine phosphate, phytin, and nucleic acid. These and similar compounds testify to the development of chemical research.

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Table 1.—*Fertilizer materials available for use in 1900*

Nitrogen sources		Phosphoric acid	Potash
Inorganic	Organic		
Ammonium sulphate. Sodium nitrate.	Cottonseed meal. Dried blood. Fish scrap. Tankage. Castor pomace. Rough ammoniates.	Superphosphate (then called acid phosphate). Precipitated phosphate. Basic slag.	Potassium chloride. Potassium sulphate. Kainite. Manure salts. Sulphate of potash-magnesia.

Table 2.—*Fertilizer materials used or proposed for use in 1936* [1]

Nitrogen sources		Phosphoric acid sources	Potash sources
Inorganic	Organic		
Ammonium sulphate. Sodium nitrate. Calcium nitrate. Potassium nitrate. Ammonium chloride. Ammonium phosphate. Ammonium nitrate. Cal-Nitro.[2] Nitro-Chalk.[2] Leunasalpeter. Potassium ammonium nitrate. Ammo-Phos A. Ammo-Phos B. Nitrophoska.[3] Diammonium phosphate. Ammonia, anhydrous liquor. Nitrogen solution II. Crude nitrogen solution. Ammonium bicarbonate.	Cottonseed meal. Dried blood. Fish scrap. Tankage. Castor pomace. Cyanamide. Urea. Calurea. "Milorganite." "Nitroganic." Urea-ammonia liquor. Rough ammoniates.	Treble superphosphate (45 to 48 percent). Superphosphate (16 to 20 percent). Monoammonium phosphate. Ammo-Phos A. Ammo-Phos B. Ammoniated superphosphate. Precipitated phosphate. Diammonium phosphate. "Oberphos." Calcium metaphosphate. Potassium metaphosphate. Calcined phosphate. Calcium pyrophosphate. Dimagnesium phosphate. Trimagnesium phosphate. Monocalcium chlorophosphate. Fused phosphate. Monopotassium phosphate. Monosodium phosphate.	Potassium chloride. Potassium sulphate. Kainite. Manure salts. Sulphate of potash-magnesia. Potassium nitrate. Potassium carbonate.

[1] Not intended to represent a complete list. There are other compounds, particularly of foreign production, that are not included. Most of the compounds listed have been tested under greenhouse and field conditions to determine their nutrient value for agricultural crops.
[2] Cal-Nitro and Nitro-Chalk are essentially the same, the former being sold by German interests and the latter by English. Both are mixtures of ammonium nitrate and calcium carbonate.
[3] Complete fertilizer.

Some interesting studies of new organic materials—called organophosphates—have been reported by Spencer and Stewart of the Nevada Agricultural Experiment Station. They have conducted extensive studies of what has been designated "positional availability"—that is, the location of soil nutrients with respect to the ability of plants to reach and utilize them. Stewart (*388*), in explaining the significance of such compounds, including calcium sorbitylphosphate, calcium glycolphosphate, calcium glycerophosphate, calcium glucose phosphate, and others for fertilizer use, states:

It has been clearly shown that the ordinary forms of superphosphates, when applied to the soil, are fixed in the soil at or near the surface of the soil. At the same time the roots of the plants penetrate deeply into the soil, far beneath the applied fertilizer materials, and, under these conditions, only a portion of the root system of the plant is in contact with the applied fertilizer, and we have shown that under these conditions, the plant cannot secure a sufficient amount of nutrient for the best production of growth. . . . We have shown that this problem thus

created may be solved by the application of the well-known principle in organic chemistry, that the introduction of a hydroxyl group into the various forms of inorganic phosphates confers water solubility upon the resulting compounds, and will permit those compounds to retain their water solubility in contact with the various soil particles.

The different materials mentioned are not commercially available at the present time, but if they are found to be worth while as nutrient materials for plants methods will probably be found to insure comparatively low production costs, just as happened with urea.

Prior to the World War potash required for fertilizer in the United States was obtained almost entirely from Europe. During the war the blockade of Germany cut off potash supplies, since that country was the chief source of potash used in the United States. Stocks on hand were used up to such an extent that crops suffered, and in a number of sections well-recognized cases of potash hunger developed. Notably was this true with cotton, potatoes, and a number of special truck crops. As a result of this experience serious efforts were made to locate sources of potash in the United States and to develop them commercially. Some potash was produced as a byproduct of blast furnaces, cement mills, and distilleries, and from natural salines and seaweeds. Because of the limited supply and high cost of production, potash so produced sold at exceedingly high prices. After the war, when European potash reappeared on the American market at prices comparable with the pre-war prices, the American producers, unable to meet the competition, ceased production with the exception of one company producing potassium chloride from the brines of Searles Lake, Calif.

In 1923, which may be considered the first normal post-war year so far as potash is concerned, domestic producers supplied approximately 9 percent of the potash materials consumed in fertilizers. By 1928–30 domestic production accounted for 16 percent of that used in fertilizers. The period 1931–35 not only marked the development and placing into production of the potash mines of New Mexico, but also those of Spain and the Union of Soviet Socialist Republics. The competition between foreign interests and the American industry for the American market resulted in potash prices for 1935 averaging approximately 57 percent below those of 1928–30.

The proportion of the home market supplied by the domestic producers increased continuously, with the exception of 1934, until in 1935 they supplied about 50 percent of the total potash used in fertilizers. During this period the total potash consumed in fertilizers increased 23 percent from an average of 368,000 tons of potash (K_2O) in 1928–30 to 453,000 tons in 1935, of which the domestic industry supplied 225,000 tons, or an amount greater than was consumed by the entire American fertilizer industry in 1923. The successful attempts to establish a domestic potash industry can be better appreciated by comparing records of production in the United States for 1934, 1935, and 1936 with imports from foreign sources for the same years (table 3).

In 1936 domestic production of potash exceeded foreign importations by more than 40,000 tons. Comparing this with any year before the World War, it will be found that until then importations accounted for

Table 3.—*Production of potash (K_2O) in the United States compared with importations from abroad, 1934–36*

Year	Produced in United States	Imported
	Tons	*Tons*
1934	144, 342	178, 533
1935	228, 556	241, 510
1936	247, 340	207, 194

most of the potash consumed for fertilizer purposes in the United States.

So far the American producers have been content to market various grades of chlorides of potash and have not attempted to supply sulphate, nitrate, or other special salts. This country should and doubtless will establish and maintain a diversified potash industry.

Thus the war made this country more independent so far as the nitrogen and potassium compounds needed by crops are concerned.

In the case of phosphorus the United States is independent of other nations and need feel no concern about phosphatic fertilizer materials for many years to come. However, our natural phosphorus resources should be conserved to the fullest extent, which means wise utilization from every standpoint. Proper mining operations, proper safeguards with reference to exportation, and proper use as fertilizer material will go far toward accomplishing this conservation.

THE ESSENTIAL ELEMENTS IN COMMERCIAL FERTILIZERS [4]

Fertilizer materials are generally understood to be commercially obtainable individual materials that contain one or more of the three essential chemical elements, nitrogen, phosphorus, and potassium, in such forms that when the materials are applied to soils, crops may make use of the elements needed for their processes of growth. In European countries, farmers customarily purchase fertilizer materials singly and apply them separately to the soil. In this country, however, it is usual for the fertilizer manufacturers to prepare mixtures from the materials and for the farmer to apply the mixed products to his land. This difference in practice is apparently primarily the result of the higher cost of farm labor in the United States.

Fertilizer materials do not consist of the fertilizing elements, nitrogen, phosphorus, and potassium, as such. They are more or less pure chemical compounds of these elements with other elements, or they are complex vegetable or animal materials. The chemical compounds may have been obtained from natural sources, as in the case of Chilean sodium nitrate; or manufactured expressly for fertilizer use, as in the case of superphosphate; or obtained as byproducts in the manufacture of other materials, as in the case of the ammonium sulphate obtained in the manufacture of metallurgical coke or city gas. The vegetable or animal materials may be of natural origin, as in the case of guano;

[4] The individual sources of fertilizer materials—nitrogenous, phosphatic, and potassic—are described in the Appendix, pp. 506 to 519.

or obtained as residues in processes for the utilization of plants and animals, as in the case of cottonseed meal and dried blood; or recovered from wastes, as in the case of sewage sludge.

Fertilizer materials are classed as nitrogenous, phosphatic, or potassic according to whether they contain nitrogen, phosphorus, or potassium as their principal or most valuable constituent. As is so often the case in the setting up of classifications, some fertilizer materials may be placed in more than one of these classes.

In the fertilizer trade it is customary to speak of fertilizer materials and mixtures as containing nitrogen, phosphoric acid, and potash instead of nitrogen, phosphorus, and potassium. Until recent years it was also the practice to speak of the ammonia instead of the nitrogen content of fertilizers, a usage that still persists in one southern State. The terms ammonia, phosphoric acid, and potash refer to compounds of nitrogen, phosphorus, and potassium, respectively. The early chemists calculated the results of their analyses in terms of these compounds, which served them as convenient means for comparing the relative values of the fertilizers they analyzed, even though these compounds of nitrogen, phosphorus, and potassium were not actually present in the fertilizers as such. The present custom is merely a relic of the earlier practice.

NITROGEN FERTILIZER MATERIALS

Classification of Nitrogen Materials

The nitrogenous fertilizer materials are classed according to the manner in which their nitrogen is combined with other elements. Some, such as sodium nitrate (nitrate of soda), have the nitrogen combined in the nitrate form. These are all characterized by ready solubility in water, and the nitrogen is more quickly utilized by most crops than is that in nitrogenous materials of the other classes (figs. 2 and 3). The nitrate form of nitrogen is, however, the most readily leached from the soil by rains because of its easy solubility and its failure to be retained or fixed in the soil to any considerable extent.

Other nitrogenous fertilizer materials, such as ammonium sulphate (sulphate of ammonia), contain their nitrogen combined in the form of ammonia or its compounds. Although they are also soluble in water, the nitrogen, known as ammoniacal nitrogen, is less readily removed from soils by leaching than nitrate nitrogen because it has a tendency to be fixed by certain of the soil constituents. Ammoniacal nitrogen can also be used directly by crops, though much of it is first converted to nitrate nitrogen through the action of soil bacteria before plants make use of it.

A third class of nitrogenous fertilizer materials comprises such animal and vegetable materials as animal tankage and cottonseed meal, which are commonly called organic ammoniates. The nitrogen in these materials is combined in the form of complex organic compounds such as proteins, which are for the most part insoluble in water. The insoluble organic nitrogen cannot be used directly by plants but must first be converted as a result of processes of decay into soluble forms. Some of these materials, such as horn meal and ground leather, decay so slowly in the soil that their nitrogen is of

FIGURE 2.—On light sandy loams, wheat is often starving for nitrogen in the early spring. The wheat on the left received a spring top dressing of soluble nitrogen, that on the right did not. (Courtesy Michigan Agricultural Experiment Station.)

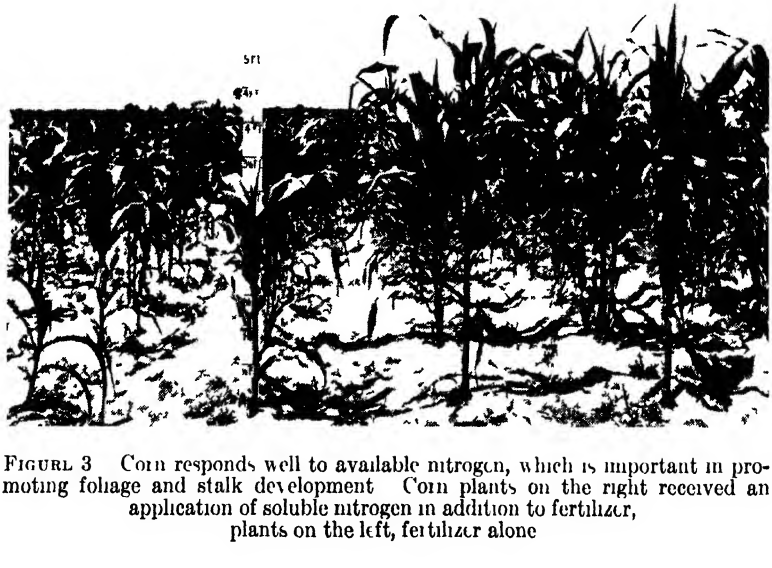

FIGURE 3. Corn responds well to available nitrogen, which is important in promoting foliage and stalk development. Corn plants on the right received an application of soluble nitrogen in addition to fertilizer, plants on the left, fertilizer alone.

little value for promoting crop growth. Fertilizer manufacturers, however, subject such inferior materials to different processes, such as treatment with superheated steam with or without the addition of sulphuric acid, or mixture with phosphate rock and subsequent treatment with sulphuric acid, to make products the nitrogen of which is mostly in forms that are readily utilized by crops. The steam-treated products are known as process tankages.

Another class of nitrogenous fertilizer materials includes the chemical compounds urea and calcium cyanamide, which contain their nitrogen in the amide form.[5] They are usually considered as organic fertilizer materials, since they are carbon compounds and are therefore classed in textbooks of chemistry among the organic compounds. They are, however, simple nonproteid compounds, manufactured from inorganic materials, and their nitrogen, unlike that of the organic ammoniates, dissolves entirely or for the most part in water. Through bacterial action in the soil the nitrogen of these compounds usually changes quickly to the ammoniacal and nitrate form.

Nitrogen Availability

Much time and energy have been spent in endeavors to devise chemical methods for determining the extent to which the nitrogen in fertilizers is "available," or readily made use of by plants. It is generally conceded that the nitrogen that is readily soluble in water is available. This includes nitrate nitrogen, ammoniacal nitrogen, and amide nitrogen, as well as a portion of the organic nitrogen contained in the organic ammoniates. The nitrogen in the organic ammoniates that is not dissolved by water is called water-insoluble organic nitrogen. Two procedures have been devised for obtaining an approximate idea of the value of this nitrogen to plants. They do not, however, measure the availability of the nitrogen but simply help to distinguish between the better and poorer sources of water-insoluble organic nitrogen, and it is generally admitted that the available nitrogen can be measured only after carefully conducted vegetation experiments with plants.

In the neutral permanganate method, the material, to which powdered rock phosphate has been added and from which the water-soluble nitrogen has then been removed, is digested under specified conditions with a solution of potassium permanganate containing sodium carbonate.[6] The nitrogen that goes into solution during the digestion is called active nitrogen and is considered to be more available to plants than that which resists the action of the permanganate.

In the alkaline permanganate method, a solution containing potassium permanganate and caustic soda is substituted for the solution of potassium permanganate and sodium carbonate, and the ammonia produced during the digestion is determined. In this method, not only must the water-soluble nitrogen in the material pass into solution, but in addition it must be converted to ammonia to be considered active nitrogen. The alkaline permanganate method therefore always

[5] Amides are compounds resulting from replacement of one or more atoms of hydrogen in ammonia (NH_3) by acid radicals. Urea is $CO(NH_2)_2$. The amides are classified as primary, secondary, and tertiary, depending on how many atoms of hydrogen are replaced.

[6] Digestion is conducted by immersing the container in a steam or hot-water bath for a period of 30 minutes.

gives lower results for active nitrogen than does the neutral permanganate method.

The two permanganate methods are customarily used to distinguish between the better and poorer sources of water-insoluble nitrogen in the organic ammoniates that have been employed in the preparation of mixed fertilizers. Such methods are employed when the water-insoluble nitrogen in the mixture amounts to 0.3 percent or more of the weight of the fertilizer. When the water-insoluble nitrogen shows an activity of less than 50 percent by the alkaline method and less than 80 percent by the neutral method, it is classed as an inferior source. It has been found that the use of either method alone may result in the condemnation of good materials; thus, the alkaline method gives comparatively low activities for the water-insoluble nitrogen of cottonseed meal, castor pomace, and Peruvian guano, which are recognized to be good sources of nitrogen. This necessitates the use of both methods before classifying a given material as inferior.

A comparison of the availabilities of the nitrogen of a series of organic nitrogenous materials as determined by vegetation tests, with the activities as determined by the permanganate methods, is given in table 4, from Wiley's Principles and Practice of Agricultural Analysis (*466, p. 310*).

Table 4.—*Availability of water-insoluble nitrogen by vegetation experiments and activity*

Source of nitrogen	Average relative availability by vegetation experiment [1]	Comparative activity by—		Source of nitrogen	Average relative availability by vegetation experiment [1]	Comparative activity by—	
		Alkaline permanganate method	Neutral permanganate method			Alkaline permanganate method	Neutral permanganate method
Dried blood:		*Percent*	*Percent*			*Percent*	*Percent*
Red	80	71	98	Process tankage	57	56	82
Dark	92	84	94	Dry ground fish	77	72	97
Foreign process tankage	53	48	79	Cottonseed meal	74	59	93
Hoof meal	78	80	94	Castor pomace	80	61	90
Peruvian guano	90	44	99	Packing-house tankage:			
Milorganite	70	62	80	A	74	73	91
Imported process tankage	51	49	94	B	81	60	100

[1] Dried red blood at 80 basis. Crop grown, Japanese millet.

Composition of Nitrogen Fertilizer Materials

The principal nitrogenous fertilizer materials on the market, together with their approximate contents of nitrogen and its forms, are given in table 5. Although fertilizer consumers can employ most of these as well as a number of other less important materials, only the fertilizer manufacturers can afford to make the large investments necessary for the machinery and other equipment required for the utilization of the high-nitrogen liquid products—anhydrous liquid ammonia, etc.—listed at the end of the table, which are sold only in tank-car lots for fertilizer-manufacturing purposes.

Table 5.—*Nitrogen content of principal commercial fertilizer materials*

Material	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Amide nitrogen
	Percent	*Percent*	*Percent*	*Percent*
Sulphate of ammonia	19.5-21.2			
Nitrate of soda		15.4-16.5		
Nitrate of potash		12.6-13.5		
Nitrate of soda-potash [1]		13.7-15.5		
Calcium cyanamide [2]				21.0-23.7
Urea				46.0-46.2
Ammonium sulphate-nitrate	19.5	6.5		
Cal-Nitro [3]	7.8-12.5	7.8-12.5		
Ammo-Phos [4]	10.4-11.7			
Do	15.8-16.8			
Calurea [5]		6.8		27.2
Calcium nitrate [6]		13.0-15.5		
Animal tankage			5.5-10.0	
Dried blood			6.0-14.0	
Fish scrap, dried			6.5-10.0	
Cottonseed meal			5.3- 7.5	
Castor pomace			4.0- 7.0	
Process tankages			6.5-10.0	
Sewage sludge, activated			4.9- 7.5	
Garbage tankage			3.3	
Cocoa shell meal			2.5	
Ground bone and bonemeals			0.7- 5.3	
Tobacco stems			1.3- 1.6	
Anhydrous liquid ammonia	82.2			
Aqua ammonia	20.5-23.5			
Urea-ammonia liquor-A [7]	30.4			15.1
Urea-ammonia liquor-B [7]	25.2			20.1
Crude nitrogen solution [8]	37.0	7.3		
Nitrogen solution II [9]	27.0	10.5		

[1] Often sold as nitrate of potash or Chilean nitrate of potash.
[2] Usually sold under the trade name "Cyanamid."
[3] Trade name for a commercial product consisting of ammonium nitrate mixed with calcium carbonate.
[4] Trade name for 2 commercial products. One is an ammonium phosphate containing approximately 11 percent of nitrogen and 48 percent of phosphoric acid; the other consists of ammonium phosphate and ammonium sulphate and contains approximately 16 percent of nitrogen and 20 percent of phosphoric acid.
[5] Trade name for a commercial product comprising the compound, calcium nitrate-urea.
[6] Also called nitrate of lime.
[7] Trade name for a commercial product containing urea and ammonia dissolved in water.
[8] Trade name for a commercial product containing sodium nitrate and ammonia dissolved in water.
[9] Trade name for a commercial product containing ammonium nitrate and ammonia dissolved in water.

Relative Merits of Nitrogen Fertilizer Materials

Sodium nitrate and ammonium sulphate are undoubtedly the most widely used nitrogen fertilizer materials at the present time. The results of experimental findings have given both of these materials a high evaluation, and furthermore have shown how and when both should be used to best advantage. In large measure this high evaluation applies also to many of the synthetic materials more recently proposed for fertilizer use, such as ammonium chloride, ammonium nitrate, ammonium phosphate, urea, and various other nitrogen fertilizer materials. A number of the agricultural experiment stations in cooperation with the United States Department of Agriculture have conducted field experiments to compare different nitrogen sources and, in general, report pretty much the same results with all materials when compared as individual sources of nitrogen in complete fertilizer mixtures.

As pointed out elsewhere, the so-called organic ammoniates, such as cottonseed meal, dried blood, fish scrap, tankage, etc., render excellent support to the more available nitrogen materials, such as nitrate of soda, ammonium sulphate, and urea. The latter are quickly avail-

able to crops, whereas the organic ammoniates have to go through a decomposition process whereby their organic nitrogen combinations are converted through bacterial action to ammonia nitrogen and then to the nitrate form. This means a slower availability of the organic fertilizer materials, but it also means that they furnish a continuous supply of available nitrogen, which is considered an important factor in fertilizer practice. However, the higher cost of nitrogen in the organic ammoniates, because of the utilization of the materials for feeding purposes, has very considerably reduced the demand for them as fertilizers in recent years, except for special crops.

PHOSPHATIC FERTILIZER MATERIALS

Classification of Phosphatic Fertilizer Materials

The phosphatic fertilizer materials contain phosphoric acid in different forms. The favorable influence of phosphoric acid fertilization upon plants is illustrated by figures 4 and 5. After this favorable influence became known, it was discovered that different phosphates might have the same phosphoric acid content and yet not have the same action; in fact, that they frequently affected the growth of crops to a quite different extent. It was found that the phosphoric acid in phosphates of organic origin, such as bones, had a more favorable influence on crop yields than that in raw mineral phosphates of the same degree of fineness, because of the more readily soluble condition of the former.

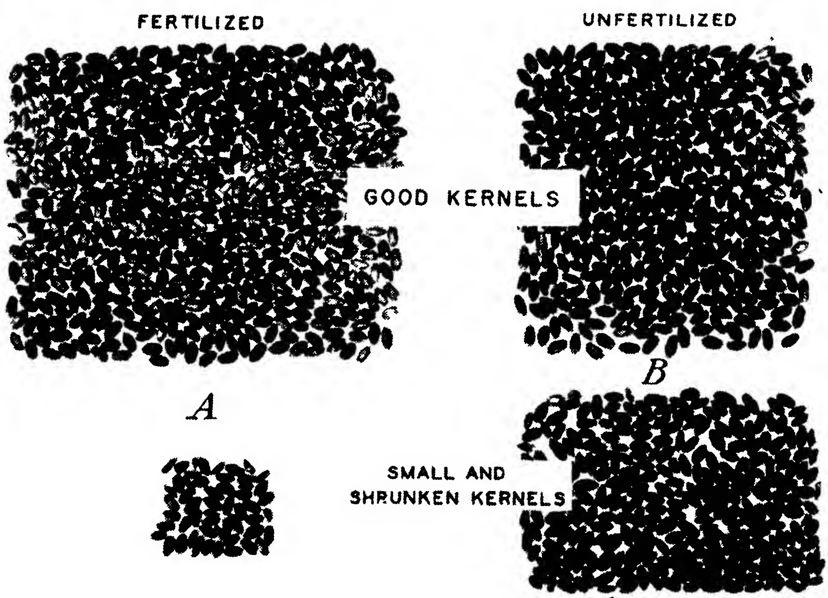

Figure 4.—A suitable combination of fertilizer materials furnishing the elements nitrogen, phosphorus, and potassium results in better grain: *A*, Wheat kernels from fertilized land, *B*, from unfertilized land. Same weight of wheat in each case. (Courtesy Michigan Agricultural Experiment Station.)

FIGURE 5.— An application of a phosphatic fertilizer material to sugar beets pays on phosphorus-deficient soil. Sugar beets on right benefited tremendously from such treatment. Those on left grown on unfertilized land.

The more pronounced action of the phosphates of organic origin was explained by the assumption that in these phosphates the individual particles of the calcium phosphate are separated from each other by organic substances and that upon the decomposition of the organic matter they are exposed and become more susceptible to the action of soil agents, such as water and carbon dioxide, than do the less finely divided particles of the mineral phosphate. The dissolution of the phosphates of organic origin is also promoted by the products of the decomposition of the organic matter, since those products have a solvent action upon the calcium phosphate. Thus it was shown that when bonemeal was mixed with water and allowed to putrefy, phosphoric acid passed into solution; and that the oxalic acid in guano would free the phosphoric acid contained therein from its combination with calcium.

The solution of the phosphoric acid is also facilitated by the presence in the soil of substances having an acid reaction, since calcium phosphate is fairly soluble in weak acids. Furthermore, such acid-reacting substances as carbon dioxide, excreted by the roots of living plants, have a solvent action upon the phosphate particles in their immediate vicinity. Carbon dioxide, which is continually present in the soil where organic substances are always decomposing, has been shown

by the experiments of many investigators to attack all phosphates of calcium more or less.

Soon after the application of bones to the soil to provide plants with phosphoric acid came into vogue, it was observed that the finer the material the greater was the effect. The proposal of Liebig in 1840, therefore, that the insoluble phosphoric acid in bones be rendered soluble by means of sulphuric acid was soon widely put into practice, since superphosphate thus produced was soluble and could mingle much more intimately with the soil than that in an insoluble state. For the purpose of estimating the value of superphosphate a distinction was made between the phosphoric acid in water-soluble form and that still in the original or insoluble form; much greater value was ascribed to the water-soluble phosphoric acid while, so far as commercial determination of price was concerned, little or no value was attached to the insoluble phosphoric acid. Liebig's suggestion was soon followed by one emanating from Sir John Lawes, of the Rothamsted Experiment Station, in England, that phosphate rock likewise be treated with sulphuric acid. This marked the beginning of the superphosphate industry.

Not long after superphosphate from mineral phosphates appeared on the market, it was discovered that the phosphoric acid rendered soluble by sulphuric acid made a more or less rapid return to an insoluble form, so that in a few months the water-soluble phosphoric acid had at times diminished to but one-third of the original quantity. This circumstance proved quite disconcerting to chemists, manufacturers, and consumers since the commercial value of the product at that time depended primarily on the content of water-soluble phosphoric acid. It was soon found, however, that when applied to the soil the phosphoric acid that had been water-soluble and had become water-insoluble (variously called retrograde, regenerated, reduced, or reverted phosphoric acid) exhibited a more beneficial effect on crops than that which had never been water-soluble, because it was very finely divided throughout the whole mass and therefore offered a large surface for attack by various agents in the soil. In trying to find a means for determining this phosphoric acid analytically, chemists discovered that it dissolved in an ammonium citrate solution. By this time, as a result of vegetation tests, the reverted, or citrate-soluble, phosphoric acid began to be considered of equal value with the water-soluble phosphoric acid, and the value of a superphosphate or other fertilizer material, so far as phosphoric acid was concerned, was based on the quantity of available, i. e., water-soluble plus citrate-soluble phosphoric acid that it contained. This evaluation has continued to hold up to the present time, with the single exception of phosphoric acid in basic slag. The forms of phosphoric acid that are not soluble in water and ammonium citrate solution are considered of practically no agricultural value.

Shortly after the development in 1878 by Thomas and Gilchrist of the basic Bessemer process for converting pig iron into steel while simultaneously removing the phosphorus, the slag produced in the process was used as a liming material for acid and lime-deficient soils. But it was soon recognized that the effectiveness of the phosphoric acid in the basic slag was often only slightly less than that of the

phosphoric acid in superphosphate and also that its effectiveness became the greater the more finely the slag was ground. Vegetation tests showed, however, that basic-slag meals of different origins were of quite different effectiveness as regards plant growth. It was originally thought that the ammonium citrate method could serve as a means for evaluating the effectiveness of the phosphoric acid in such slags, since much of this phosphoric acid is citrate-soluble. Experience has shown, however, that the method, although applicable to the reverted phosphoric acid in superphosphates, is of little value when applied to phosphatic slags, probably because of their different chemical constitution, which interferes with the solvent action of the citrate solution. After much experimental work, the phosphoric acid of Thomas Bessemer slags that was soluble in a 2-percent citric acid solution was found to correspond to the availability figures as established by vegetation tests, and the available phosphoric acid in basic slags is now considered to be that which dissolves in this solution.

It should be kept in mind that the chemical methods for the determination of water-soluble, citrate-soluble, and citric acid-soluble phosphoric acids have been developed in purely empirical ways. Whereas the total phosphoric acid in a fertilizer material is a definite fixed quantity and different methods for its determination should give no appreciable variation in results, the water-soluble, citrate-soluble, and citric acid-soluble phosphoric acids are rather arbitrary quantities and are dependent on a number of factors, such as time of digestion, degree of fineness of the sample, kind and quantity of solvent, agitation, etc., which have been so chosen as to give results that harmonize with vegetation tests.

Some phosphatic materials, such as ammonium phosphate, have their phosphoric acid entirely or mostly in water-soluble form, which is readily usable by crops. In other materials, such as precipitated phosphate, all or most of the phosphoric acid though practically water-insoluble is nevertheless citrate-soluble (or in the case of basic slag, citric acid-soluble) and still readily available for use by plants. Still other materials have much or most of their phosphoric acid in forms that are even less soluble. Since they are contained in the residue that remains when the chemist dissolves out the citrate-soluble phosphoric acid from fertilizers, these forms of phosphoric acid are collectively known as citrate-insoluble phosphoric acid or simply as insoluble phosphoric acid. Their sparing solubility is often such that they cannot be readily utilized by plants, though under some conditions insoluble phosphoric acid is rendered sufficiently soluble in the soil to be utilizable by crops. Acid soils, particularly, favor their solution.

In soils that contain considerable organic matter, certain products of the decay increase the solubility of the insoluble phosphoric acid so that it may be more readily taken up by crops. Of the materials with considerable quantities of insoluble phosphoric acid, those that contain organic matter and are therefore also valuable as nitrogenous materials—such as bonemeal and fish scrap—are most used without previous chemical treatment for fertilizer purposes; but ground or other finely divided forms of phosphate rock are also employed to some

extent. Only the total quantity of phosphoric acid in such materials is customarily determined.

The principal phosphatic fertilizer materials with their approximate phosphorus content expressed as phosphoric acid (P_2O_5) are listed in table 6.

Table 6.—*Phosphoric acid (P_2O_5) content of fertilizer materials*

Material	Available phosphoric acid	Total phosphoric acid	Material	Available phosphoric acid	Total phosphoric acid
	Percent	*Percent*		*Percent*	*Percent*
Superphosphate	13.5–22.0		Bonemeal and ground bone		17.0–30.0
Double (treble, triple) superphosphate	40.0–50.0		Animal tankage		5.0–18.0
Ammo-Phos[1]	20.0–22.8 48.0–52.6		Garbage tankage		4.5
			Fish scrap, dried		5.0–8.0
Precipitated phosphate	37.0–42.0		Ground phosphate rock and other phosphatic mineral products		12.0–35.0
Basic slag	[2] 5.0–20.0				
Sewage sludge	2.0–3.6				

[1] See footnote 4, table 5.
[2] The basic slag produced in this country is sold on the basis of a content of 8 percent total phosphoric acid.

Relative Merits of Phosphatic Fertilizer Materials

From an industrial standpoint the principal phosphatic fertilizer materials used in the United States are superphosphate (ordinary strength 16- to 20-percent phosphoric acid), treble superphosphate (40- to 48-percent phosphoric acid), and ammonium phosphate, chiefly monoammonium phosphate (11-percent nitrogen, 48-percent phosphoric acid), which contains nitrogen in the ammoniacal form. To these can be added bonemeal (raw and steamed), basic slag, and finely ground rock phosphate, largely because each of these three is more suitable for direct application to the soil than for the preparation of complete fertilizer mixtures.

The results of many years of experimental studies, coupled with practical experience and observation, have definitely established the value of the different superphosphates. Enough has been done in an experimental way with ammonium phosphate to have determined that it is an excellent source of phosphorus, particularly adaptable to the preparation of concentrated fertilizers or for direct application to the soil where its individual use is indicated as being desirable. Ammonium phosphate, in common with certain other ammonia compounds, has a tendency to increase soil acidity, and it may be necessary to lime the soil or add some neutralizing agent such as ordinary or dolomitic limestone to counteract this potential acidity.

Basic slag, owing to its high lime content, is not used in mixed fertilizers, for fear of liberating ammonia through chemical interaction with the ammonium salts incorporated with the mixture. However, it has been evaluated as a good source of phosphoric acid for heavy soils acid in reaction and for soils deficient in available lime. It promotes the growth of meadows and pastures and in common with other phosphatic fertilizer materials encourages the germination and development of various root and tuber crops as well as other phosphorus-responsive crops.

Bonemeal, either raw or steamed, when sufficiently fine, rates well as a source of phosphorus and to a considerable degree its value is increased by its nitrogen content. Its lasting character and its safety make it very serviceable to greenhouse and other specialists. Because the phosphorus in bonemeal becomes available slowly, it is effective for more than one season. It is best applied to mellow soils containing an ample supply of organic matter.

POTASSIC FERTILIZER MATERIALS

All commercial potassic fertilizer materials contain their potash in water-soluble forms which can be readily absorbed by plants.

Figure 6 illustrates the effect of addition of potash to a light soil.

FIGURE 6.—On light soils potash is necessary to optimum plant growth. The millet in the pot on the left received no fertilizer; that in the center, a mixture of nitrogen and phosphorus fertilizer materials; that on the right, potash in addition.

Table 7.—*Potash (K_2O) content of fertilizer materials*

Material	Potash	Material	Potash
	Percent		*Percent*
Potassium chloride (muriate of potash)	47–61.5	Sulphate of potash-magnesia	26 –29
Potassium sulphate (sulphate of potash)	47–52	Kainite	14 –22
Potassium nitrate (saltpeter)	42.9–45.2	Cotton hull ashes	20.5–34.8
Nitrate of soda-potash [1]	13.7–16.4	Hardwood ashes	1.5– 8.0
Manure salts	19 –32	Tobacco stems	4.4– 5.4

[1] Usually sold as nitrate of potash or Chilean nitrate of potash.

The principal potassic fertilizer materials and the approximate ranges of their potash contents are given in table 7.

SECONDARY ELEMENTS IN FERTILIZER MATERIALS[7]

The different fertilizer materials contain other elements in addition to nitrogen, phosphorus, or potassium. The quantities of these elements present in a given material may vary from none or extremely little to quantities greater than those of the three elements thus far discussed. Although certain of these elements are just as essential for normal plant growth as nitrogen, phosphorus, and potassium, their presence has customarily been given little or no consideration in the use, or determination of the value, of fertilizer materials, since they were generally thought to be present in soils in quantities sufficient to meet crop requirements.

The elements calcium, magnesium, sulphur, boron, copper, manganese, zinc, and iron are of more immediate practical interest to fertilizer investigators and the fertilizer industry. The three elements calcium, sulphur, and magnesium are used by crops to a greater extent than the other secondary elements.

Ordinary superphosphate, the most extensively used of all phosphatic fertilizer materials, contains about 19 to 22 percent of calcium. Calcium is also a prominent element in most of the other phosphatic fertilizer materials, the sole exception being the ammonium phosphates, as well as in certain nitrogenous fertilizer materials, calcium cyanamide, calurea, calcium nitrate, and Cal-Nitro.

Superphosphate also contains about 10 to 12 percent of sulphur, and ammonium sulphate, the most extensively used of the nitrogenous fertilizer materials, contains about 23 percent, while sulphur is present in considerable quantity also in the potassic fertilizer materials—potassium sulphate, sulphate of potash-magnesia, and manure salts. While most ordinary commercial fertilizer mixtures contain superphosphate and ammonium sulphate as ingredients, and therefore furnish sufficient calcium and sulphur to the soil to prevent a deficiency of either element, there are other fertilizer materials that are almost completely lacking in both elements. If such materials were utilized in the production of complete fertilizers it is conceivable that their continued use would in time accelerate the exhaustion of the available calcium and sulphur naturally present in the soil to such an extent that it would be necessary to add calcium and sulphur compounds to the fertilizer to prevent the deficiency. Notable cases of sulphur deficiency have been observed and reported in connection with certain soils of Oregon and Washington. Under eastern conditions no serious case of either calcium or sulphur soil deficiency has as yet been observed under ordinary field conditions.

Magnesium deficiency in all probability has affected crop production more widely than that of any other secondary plant food. Its widespread occurrence along the Atlantic seaboard in recent years has been due primarily to two factors—(1) the use of commercial fertilizers made from materials containing very little magnesium,

[7] For a discussion of the results of deficiency of these elements in soil, see Neglected Soil Constituents That Affect Plant and Animal Development, p. 807.

and (2) increasing soil acidity resulting from the heavier use of acid-forming salts, which facilitated the leaching of magnesium from the soil. Both of these factors have tended to lower the content of available magnesium in the soil to a point below the requirements of crops.

Formerly, the main sources of magnesium in fertilizer mixtures were the low-grade potassic materials, which contained considerable quantities. These materials, once the most extensively used means for supplying potassium in fertilizers, have now been largely displaced by high-grade potassium salts that contain little magnesium. The kainite, containing about 13 percent of potash, also contained about 7 percent of magnesium; but potassium chloride, the potassic fertilizer material most used at present, with 50 percent or more of potash, generally contains less than 0.1 percent of magnesium; and potassium sulphate, with about 48 percent of potash, usually contains less than 0.5 percent of magnesium.

Although the organic ammoniates, formerly the principal sources of nitrogen in fertilizers, contained only small amounts of magnesium—about 0.5 percent in cottonseed meal, for example—nevertheless they supplied considerable quantities because of the large tonnages used. They have now been largely displaced by cheaper products containing practically no magnesium. Realizing the necessity for the addition of magnesium-containing materials to fertilizers for use on soils requiring this element, many fertilizer manufacturers have in recent years incorporated calcined kieserite, an anhydrous form of magnesium sulphate that contains about 19 percent of magnesium in water-soluble form, or sulphate of potash-magnesia (a potassic fertilizer material), which contains about 6 percent of water-soluble magnesium.

Magnesium-containing or dolomitic limestones and dolomite, which contain up to about 12 percent of water-insoluble magnesium, are also extensively employed as additions to fertilizer mixtures at present. The primary purpose, however, in many cases is not to supply magnesium but to prevent the increase in soil acidity caused by certain nitrogenous fertilizer materials. Although the magnesium in these additions is water-insoluble, a portion is rendered water-soluble as a result of chemical reactions that take place with the superphosphate of the mixtures to which they are added. It is known also that the water-insoluble magnesium in the soil becomes slowly available for use by crops, but no chemical procedure has yet been developed for determining its availability. In order to determine practical procedures, much more information is needed on the responses of different crops to different magnesium compounds. Progress is being made in this direction through field tests in many places.

There is occasional need for the addition to fertilizers of other elements in decidedly smaller amounts than calcium, sulphur, and magnesium. The necessity for the use of special materials to supply these elements to fertilizers is infrequent, yet in particular cases successful crop production is dependent on using them either as direct additions to the soil or as additions to mixed fertilizers or spray materials. The compounds being used chiefly as sources of these elements in fertilizers are manganese sulphate, copper sulphate, zinc sulphate, borax, and ferrous sulphate, all of which are water-soluble.

It is essential to keep in mind that too heavy an application of any secondary element to the soil in fertilizers may readily lead to serious crop injury. The use of compounds supplying these elements should be based on the results of actual experimentation with different crops and soils. The promiscuous use of secondary elements in fertilizer mixtures without such information is both unwarranted and uneconomical.

EVALUATION OF FERTILIZER MATERIALS DEPENDENT UPON EFFECT ON CROP GROWTH

When a new material is proposed for fertilizer use, one of the first things to determine is its effect on plant growth. Before attempting this, however, its solubility, hygroscopicity, reaction, and behavior when mixed with standard fertilizer materials are determined. When these physical properties have been found to be satisfactory, the new material is tested to determine what nutrient value it may possess. Such tests are generally initiated under controlled greenhouse conditions, pots or other containers being used to hold the soil. Suitable crop plants are grown and the new materials are evaluated in terms of standard fertilizer materials of known performance, which are utilized as controls. In this way results are obtained more quickly than is possible otherwise.

Field experiments conducted under actual field conditions, however, when properly supervised, afford the best proof in the long run. By these methods a great many of the new fertilizer materials have been evaluated by some of the State agricultural experiment stations and the Department of Agriculture. Information of this kind is essential because the commercial exploitation of a material for fertilizer use is predicated upon its having sufficient nutrient value to warrant large-scale production.

A discussion of the residual effects of fertilizer materials on soil reaction is given in the Appendix (p. 519).

APPENDIX

Description and Uses of Important Fertilizer Materials

Nitrogen Materials

AMMONIA

Ammonia (NH_3) is the basic constituent of many ammonium compounds. It is a gas containing 82.25 percent of nitrogen. There is a liquid anhydrous form obtained by compressing ammonia gas under suitable conditions as to pressure and temperature. This form of ammonia is now of importance to the fertilizer industry for the ammoniating of superphosphate either to produce base mixtures or to make complete fertilizers. Another form, aqua ammonia (NH_4OH), or ammonia liquor, results from the absorption of ammonia gas (NH_3) in water, in which it is quite soluble. Commercial grades of ammonia liquor may run as high as 30 percent of ammonia (NH_3). Various ammonium salts result when ammonia is made to react with different acids, such as sulphuric to form ammonium sulphate, phosphoric to form ammonium phosphate, and nitric to form ammonium nitrate. Anhydrous liquid ammonia is used to some extent in California for introduction into irrigation water.

AMMONIUM CHLORIDE

The ammonium salt of hydrochloric acid, ammonium chloride, is a white crystalline compound with a nitrogen content of about 26 percent. It possesses an excellent physical condition, and aside from the fact that its chlorine content may prove detrimental to certain crops, particularly tobacco and certain starch-forming plants, the results of experimental studies in the United States have shown that it compares favorably with ammonium sulphate. On account of the higher cost of hydrochloric acid, however, ammonium chloride is not being used in fertilizers in the United States.

AMMONIUM NITRATE

Ammonium nitrate is a white crystalline salt generally prepared by neutralizing nitric acid with ammonia. It is rich in nitrogen, generally having a content of this element of from 33 to 35 percent. It is quite hygroscopic, which renders it undesirable as a complete source of introgen in mixed fertilizers. In some measure a mechanical treatment termed granulation will alleviate this moisture-absorbing tendency, the granules being further protected by a light coating of oil. Another method to overcome this hygroscopic nature of ammonium nitrate consists in the preparation of a product made by mixing ammonium nitrate with calcium carbonate. This material, given the trade name "Cal-Nitro" by German interests and "Nitro-Chalk" by English producers, has half of its nitrogen in the nitrate form and half in the ammonium form. Its content of lime carbonate makes this material well adapted to soils low in lime. Strictly from the standpoint of plant food, however, it has given an excellent account of itself, largely because it contains both the ammoniacal and nitrate forms of nitrogen.

AMMO-PHOS

"Ammo-Phos" is a trade name for two commercial grades of monoammonium phosphate used as fertilizer materials and in mixed fertilizers to furnish nitrogen and phosphoric acid. Two grades, A and B, are on the market. Grade A, most commonly used for fertilizer purposes, contains about 11 percent of nitrogen and 45 to 48 percent of available phosphoric acid. Grade B contains about 16.5 percent of nitrogen and 20 percent of available phosphoric acid, being largely a mixture of ammonium phosphate and ammonium sulphate. Both grades possess an excellent mechanical condition, and extensive experimental studies with various crops on important soil types have shown them to be dependable fertilizer materials.

AMMONIATED SUPERPHOSPHATE

Ammoniated superphosphate is a product resulting from treating superphosphate with anhydrous or aqueous ammonia (aqua ammonia). The ammoniation of superphosphate is recognized as an excellent practice, because it makes for quicker curing and better mechanical condition, neutralizes acidity, adds nitrogen, reduces bag rotting and storage difficulties, and finally insures good drillability and uniform distribution.

Other materials for ammoniating fertilizer materials containing superphosphate are "Urea-ammonia liquor A" and "Urea-ammonia liquor B." Both are essentially solutions of crude urea in aqua ammonia. Urea-ammonia liquor B, however, contains a higher ratio of urea nitrogen to ammoniacal nitrogen, so that by its use more nitrogen may be introduced into the ammoniated product without reversion of the phosphoric acid to nonavailable forms. Other ammoniating solutions have been designated "crude nitrogen solution" and "nitrogen solution II," respectively. The former is a mixture of nitrate of soda (45 percent), anhydrous ammonia (45 percent), and water (10 percent). The normal composition of nitrogen solution II is by weight: Ammonium nitrate (60 percent), ammonia (20 percent), and water (20 percent). All these liquors are employed in the preparation of either base mixtures or complete fertilizers. Still more recently formamide ($HCONH_2$), containing about 30 to 31 percent of nitrogen, has been suggested as a source of nitrogen in the preparation of ammoniating solutions.[8] Recent greenhouse studies made to evaluate formamide and its hydrolytic product, ammonium formate, as nitrogen sources for plants, indicate that they compare favorably with certain standard sources of nitrogen, including ammonium sulphate and urea.

[8] When the formamide liquor is added to superphosphate the formamide hydrolyzes to form ammonium formate.

AMMONIUM PHOSPHATE

The two principal ammonium phosphates are monoammonium phosphate and diammonium phosphate, both containing two fertilizer elements, nitrogen and phosphorus. The former when comparatively pure contains about 11 percent of nitrogen and 60 percent of available phosphoric acid; and the latter 21 percent of nitrogen and 53 percent of available phosphoric acid. While both compounds have been used as fertilizer materials, particularly monoammonium phosphate in the United States under the trade name "Ammo-Phos," diammonium phosphate is preferably used with other materials owing to its tendency to lose ammonia. It is alkaline in reaction and reported cases of crop injury following its use on light sandy soils appear to have been due to the liberated free ammonia adversely affecting root development.

AMMONIUM SULPHATE

Ammonium sulphate is a salt resulting from the interaction of ammonia and sulphuric acid, the ammonia being either a volatilization product in the manufacture of coke from coal or synthesized from atmospheric nitrogen. It is also produced on a large scale in foreign countries from ammonia, gypsum, and carbon dioxide. Commercial sulphate of ammonia for fertilizer use should contain not less than 20.5 percent of nitrogen. Arcadian sulphate of ammonia differs from the ordinary commercial grade by being neutralized, dried, and screened to remove lumps. The process of manufacture—neutralizing, drying, and screening—insures excellent physical condition and uniform distribution of the material when applied to the soil.

Ammonium sulphate and sodium nitrate for many years were the chief sources of inorganic nitrogen and in large measure still are. Of all inorganic fertilizer materials ammonium sulphate is at the present time the most universally produced, being manufactured, according to report, in 15 of the leading countries of the world.

Sulphate of ammonia is used in practically the same way as nitrate of soda, and under most soil conditions just as effectively. It differs from the latter, however, in its effect on soil reaction, tending to increase soil acidity, particularly if used continuously. Its best effect is on soil not too acid in reaction. If the acidity of the soil becomes too great, harmful compounds, chiefly of aluminum, may go into solution, resulting frequently in what is termed aluminum toxicity.

This acid-forming tendency on the part of ammonium sulphate as well as other ammonium compounds may be counteracted by liming the soil to a point conducive to the greatest activity of nitrifying bacteria, or by adding enough finely ground limestone to the ammonium sulphate to offset the tendency. When this is done, sulphate of ammonia has been found to give results on a par with those from equivalent quantities of nitrogen in nitrate of soda.

CALCIUM CYANAMIDE

Calcium cyanamide, a synthetic fertilizer material, is a grayish-black powder containing considerable lime, some free carbon, and other incidental materials of no special significance. Owing to its high neutralizing power, it is decidedly suitable for soils having an acid reaction. It cannot be used too freely in mixed fertilizers because undesirable reactions ensue. However, when used at the rate of 50 to 60 pounds per ton it is a good source of nitrogen and helps considerably in providing a fertilizer mixture with a good mechanical condition as well as helping to prevent bag rotting. Commercial calcium cyanamide generally contains about 21 to 22 percent of nitrogen. A chief use in European countries as well as in the United States is for top dressing grassland.

CALCIUM NITRATE

Calcium nitrate (nitrate of lime) is a fertilizer material generally produced from the neutralization of synthetic nitric acid with calcium carbonate or limestone. In its action as a nutrient material it rates on a par with nitrate of soda, but it is more hygroscopic, which makes it somewhat more difficult to apply to the soil. Shipment in paper-lined moistureproof bags and quick application when opened have tended to make it easier to handle. When applied to the soil it behaves similarly to nitrate of soda in that it eventually tends to decrease soil acidity. For some crops, particularly if there is a low available calcium content in the soil, calcium nitrate is especially indicated. It carries about 17 percent of nitrogen and about 34 percent of lime stated as calcium oxide (CaO).

CAL-NITRO

This commercial product is described under Ammonium Nitrate.

CALUREA

"Calurea" is a trade name for a double salt prepared through the interaction of synthetic urea and calcium nitrate. It is a white crystalline product, readily soluble in water. It contains about 34 percent of nitrogen, about four-fifths of which is present as urea nitrogen, the balance in the form of nitrate nitrogen. The results of fertilizer experiments in which Calurea was used indicate it is a satisfactory source of nitrogen.

CASTOR POMACE

Castor pomace is the residue of the castor bean after the oil has been extracted. It is not used as a stock feed, being poisonous, and therefore generally can be purchased at a more reasonable cost per unit of nitrogen than materials such as cottonseed meal, dried blood, or tankage. The nitrogen content of castor pomace is in the organic form, and on an average runs about 5.5 percent, with about 1 to 1.5 percent of phosphoric acid (P_2O_5) and the same percentage of potash (K_2O). Castor pomace rates well as an organic source of nitrogen and for its good effect on the mechanical condition of fertilizers.

COTTONSEED MEAL

Cottonseed meal is a byproduct resulting from the extraction of oil from cottonseed. The remaining press cake residue is ground to give commercial cottonseed meal with a nitrogen content averaging about 7 percent (if contaminated with hulls it may be as low as 6 percent), about 2.5 percent of phosphoric acid, and from 1.5 to 2 percent of potash. Generally it is used as a partial source of nitrogen in mixed fertilizers and is popular in certain sections where special crops such as tobacco are grown. The nitrogen in cottonseed meal is relatively quickly available. It possesses an excellent mechanical condition, and a little of it goes a long way in preventing caking of fertilizer mixtures. In recent years admixtures of cottonseed meal and certain inorganic nitrogen fertilizer materials, chiefly sulphate of ammonia and nitrate of soda, have been recommended for the early spring treatment of lawns. Owing to the fact that cottonseed meal, especially the better grades, is used for stock-feeding purposes, the price is higher per unit of nitrogen than the inorganic nitrogen materials.

DRIED BLOOD

Dried blood is a byproduct of the abattoir and the packing-house industry. At the present time it is less used as a fertilizer material than in former years, owing in large measure to the demand for it for stock-feeding purposes, the resulting competition tending to raise the nitrogen cost to the consumer. The best grades of dried blood generally are not used for fertilizer purposes unless specified, the poorer off-color grades being reserved for this purpose. Ordinarily good dried blood will have a nitrogen content ranging from 12 to 14 percent down to as low as 9 percent, owing to dilution with animal parts containing less nitrogen than blood. The nitrogen of blood becomes available in a relatively short time and is prized by greenhouse specialists on this account as well as for its good mechanical condition, ease of distribution, and noninjurious action on plants.

FISH SCRAP

Fish scrap is prepared from nonedible fish and offal from fish canneries. After the fish have been cooked with steam and the oil pressed out, the residue is dried and ground and sold for fertilizer and other purposes. Another product, designated "acidulated fish scrap" or "acid fish," represents residual fish waste treated with an acid to prevent decomposition. Both the raw and the acidulated fish scrap possess a good mechanical condition and their nitrogen becomes available to crops in a relatively short time. Raw fish scrap contains on an average about 8 percent of nitrogen and 6 percent of phosphoric acid, and acidulated fish, 5 percent of nitrogen and 4.5 percent of phosphoric acid.

GARBAGE TANKAGE

Garbage tankage is a low-grade organic nitrogen material resulting from the treatment of household, hotel, and restaurant kitchen wastes in about the same

way as slaughterhouse wastes. It contains on an average about 3 percent of slowly available nitrogen, 3.5 percent of phosphoric acid, and 0.75 percent of potash. Garbage tankage is dry and bulky, making its chief value that of a conditioner for fertilizer mixtures.

LEUNAPHOS

"Leunaphos" is a trade name for a mixture of diammonium phosphate and ammonium sulphate. It carries 20 percent nitrogen in the ammonium form, and 20 percent available phosphoric acid (P_2O_5). Its most extensive use as a fertilizer material has been in Germany.

LEUNASALPETER

"Leunasalpeter" (26 percent nitrogen) is a trade name for a double salt of ammonium sulphate and ammonium nitrate (ammonium sulphate-nitrate), with one-fourth of the nitrogen content in the nitrate form and the remainder in the ammonia form. It is manufactured in Germany in large quantities for fertilizer use. Chemically it is a double salt, not a simple mechanical mixture of the two salts. It has given good results in field and greenhouse tests in comparison with standard nitrogen sources.

LINSEED MEAL

Linseed meal is a material resulting from the pressing of flaxseed to obtain linseed oil. The press cake is afterward ground. The demand for it for stock-feeding purposes is sufficient to make it too expensive a nitrogen source for fertilizer use, except on a very limited scale. It behaves similarly to cottonseed meal and contains approximately 5.5 percent of nitrogen. In addition, there is a small percentage (1.7) of phosphoric acid (P_2O_5), and about 1.3 percent of potash (K_2O).

POTASSIUM NITRATE

Potassium nitrate is one of the earliest discovered chemical nitrogen compounds for both agricultural and industrial uses. From the standpoint of natural supplies only small deposits of potassium nitrate occur in different parts of the world. These deposits have no particular value for commercial exploitation. The raw material from which refined sodium nitrate is produced--caliche--contains from 2 to 3 percent of potassium nitrate. The latter constitutes the main source of this salt. A crude form of potassium nitrate containing both sodium and potassium nitrates, constitutes the commercial grade most frequently used as a fertilizer material. This has a nitrogen content of 14 to 15 percent and a potash content (K_2O) of about 14 percent. When refined or produced synthetically, potassium nitrate contains close to 14 percent of nitrogen and about 45 percent of potash.

Potassium nitrate is much less hygroscopic than other fertilizer nitrates and has the advantage of carrying two fertilizer elements. An evaluation of potassium nitrate, in greenhouse and field tests, indicates it is a valuable fertilizer material. This is primarily due to its nitrogen being in the nitrate form and therefore immediately available to crop plants, and also to its better retention than sodium nitrate by the soil.

SEWAGE SLUDGE

Sewage sludge is a product resulting from the treatment of city or town sewage. The two chief methods of treating sewage are the Imhoff and the activated. The activated sludge method gives a higher grade product and one better adapted to fertilizer use, averaging about 5 percent of nitrogen and 3.5 percent of phosphoric acid. Imhoff sludge contains on an average only 2.5 percent of nitrogen and about 1 percent of phosphoric acid. Dried activated sludge is produced and marketed by the sewerage commission of the city of Milwaukee and sold under the trade name "Milorganite." It is also being produced by the city of Pasadena, Calif., and sold under the trade name "Nitroganic." Activated sewerage products are made from sewage free from grit and coarse solids, and aerated after being inoculated with micro-organisms. The resulting flocculated organic matter is withdrawn from the tanks, filtered with or without the aid of coagulants, dried in rotary kilns, ground, and screened.

SODIUM NITRATE (NITRATE OF SODA)

There are two principal commercial sources of sodium nitrate, (1) Chilean sodium nitrate or saltpeter, and (2) synthetic sodium nitrate (made in the United States as Arcadian sodium nitrate). Chilean nitrate is a relatively pure salt containing approximately 95 to 98 percent of sodium nitrate, equivalent to 15.6 to 16 percent of nitrogen. Synthetic sodium nitrate, containing 16 to 16.25 percent of nitrogen, is made from synthetic ammonia (this being converted to nitric acid) and sodium carbonate.

Sodium nitrate is one of the main sources of available nitrogen, having been used extensively as a fertilizer material in the United States for practically a century. Its popularity is due primarily to the fact that much experimental evidence coupled with the practical experience of farmers, fruit growers, and vegetable crop specialists, has clearly shown it to be a quick-acting, dependable source of nitrogen. Its rapid solubility in the soil moisture insures immediate availability to crop plants, thereby rendering this fertilizer material particularly adaptable to the growing of truck crops, and as a supplementary treatment for cotton, corn, small grains, and tobacco. Sodium nitrate is used as an ingredient in complete fertilizer mixtures, but as a general rule the results of field studies comparing different carriers of nitrogen indicate that a better response is obtained from having a combination of nitrogen materials rather than one source alone. A mixture of sodium nitrate and ammonium sulphate is much to be preferred to either alone.

Sodium nitrate is used principally in three ways: (1) Direct application to the soil as side or top dressing, (2) in commercial and home-prepared fertilizer mixtures, and (3) in the production of greenhouse crops. Used properly as to rate and time of application, sodium nitrate influences crop quality, especially in the case of leafy crops or those to be eaten raw for salad purposes. A mixture of equal parts of sodium nitrate and ammonium sulphate diluted with cottonseed meal makes a good early spring lawn treatment, providing the grass with a supply of quickly available nitrogen. The properties of sodium nitrate in relation to soils and crops are discussed in detail in a publication of the United States Department of Agriculture (*253*).

TANKAGE

Tankage is the refuse from slaughterhouses, and from all other sources furnishing dead animals or waste parts. After being cooked with steam, generally under pressure, and the fat pressed out or skimmed off, the residue is dried and ground. The composition of tankage varies, chiefly in accordance with the proportion of bone to meat, etc. A good grade of tankage will contain as much as 10 percent of nitrogen; lower grades scale down to 5 percent. It also has a phosphoric acid content of from 9 to 14 percent. Tankage possesses a good mechanical condition, and so far as nitrogen availability is concerned it is practically on a par with cottonseed meal and similar byproduct organic ammoniates.

UREA

Urea is a white crystalline organic compound. It is produced synthetically on a large scale in the United States as well as in Germany. Commercial urea is relatively pure, containing about 46 percent of nitrogen against 46.65 percent for pure urea. Urea, the nitrogen of which is classified as nonproteid organic nitrogen (the amide form), is water-soluble. In availability to crop plants it rates high, and the results of experimental studies conducted under field conditions with different crops on a wide range of soil types show it to be an excellent fertilizer material. While urea is fairly hygroscopic, recent methods of production largely offset this.

MISCELLANEOUS NITROGEN MATERIALS

There are a number of refractory organic materials containing nitrogen—refractory in the sense that they resist decomposition to a marked extent. A list of such materials includes hair, hide scrapings, hoof and horn meal, leather meal, wool waste, feathers, shoddy and felt, scrap fur, silk waste, etc. These are termed rough ammoniates. Such materials have to be suitably treated in order to possess more rapid availability. This can be done by adding one or more of the organic materials to phosphate rock and treating the mixture with sulphuric acid in the same way superphosphate is made—ordinarily termed the "wet-mixed

process." By the action of the sulphuric acid on the nitrogenous materials the unavailable nitrogen is converted into an available form, partly ammonium sulphate and partly organic compounds that are readily transformed in the soil and made assimilable by plants.

By such a method it is practicable to convert inert materials into forms furnishing appreciable quantities of valuable plant food, and at the same time to produce the primary product, superphosphate. The acidulation process leads to the production of base goods, or as commonly designated in Europe, ammoniated superphosphate, a product differing from the one obtained when superphosphate is treated with ammonia.

There are also various vegetable and fruit wastes termed pomaces, including chiefly apple pomace—the pulp left after apples are pressed for cider—tomato, pumpkin, and cranberry pomaces. Generally speaking, such materials must be used locally and in some cases should be composted before using. If used in any great quantity the precaution of liming should be taken to neutralize any acidity that might develop.

Phosphatic Materials[9]

BASIC SLAG

Basic slag is a byproduct obtained in the manufacture of steel by the basic Bessemer and basic open-hearth processes. Open-hearth basic slag, as a rule, contains less phosphorus and is more variable in composition than that produced by the Bessemer process. The slags from the two processes also differ greatly in the availability of the phosphorus as measured by the solubility in citric acid and by vegetative tests. This difference is due to the practice in many open-hearth plants of adding fluor spar to the furnace charge for increasing the fluidity of the slag and aiding in the desulphurizing of the iron. The availability of the phosphoric acid in basic slag increases with the fineness of grinding and with the silica content, and decreases as the fluorine content increases. Basic slag made without the addition of fluor spar is generally more effective on acid soils than superphosphate; the reverse is true on alkaline soils. As a result of its free lime content, basic slag is of special value for the reclamation of acid soils, particularly such as are rich in organic matter, like many marsh or muck soils. It has also proved very beneficial to clover, alfalfa, and the grasses, being particularly suitable as a top dressing for old meadows and pastures. Its availability to soybeans at the New Jersey Agricultural Experiment Station was found to be approximately equivalent to that of superphosphate (*37*). Although fluor spar slags generally give somewhat increased yields, they are less effective than the more soluble basic slags.

BONES

The use of bones as a fertilizer material to supply phosphoric acid and some nitrogen antedates the use of rock phosphate or superphosphate by a great many years. While it was recognized in ancient days that an application of bones did something toward increasing crop yields, there was no explanation of the effects until the discovery of the element phosphorus by Gahn in 1769, which disclosed that phosphorus is a vital constituent of bones. The earlier idea was that the fertilizer value of bones was due to certain organic constituents, fat and gelatine. It is now known that bones are rendered more efficient for fertilizer purposes when these organic substances are largely removed by steaming or other treatment. This indicates that the effect of bones is due chiefly to their calcium phosphate content, although some benefit may be ascribed to the nitrogenous organic constituents.

Acidulated bone, also termed "bone superphosphate," contains on an average about 14 or 15 percent of available phosphoric acid and from 1 to 2 percent of nitrogen. To Sir John Lawes, founder of the famous Rothamsted Experiment Station at Harpenden, England, goes the credit for developing a process of treating bones with sulphuric acid to render the phosphoric acid more available. His experimental studies more than a century ago proved the value of such treatment. This material has at the present time only historical value, for the reason that the same treatment when applied to mineral phosphates, generally designated rock phosphates, produces equivalent results in rendering the phosphoric acid of the

[9] Ammonium phosphate and Ammo-Phos, sources of phosphoric acid as well as of nitrogen, are described under Nitrogen Materials, pp. 508 and 507.

raw rock available. Owing to the competition of superphosphate, acidulated bone has very little, if any, commercial significance at the present time.

Bonemeal (raw) results from grinding bones to a fine state of division without other treatment. It is a carrier of both nitrogen (averaging 3.5 percent) and phosphoric acid (ranging from 20 to 25 percent). The use of raw bone as a fertilizer material goes back many years and its value depends largely upon how finely the bones are ground. It is a "safe" material and can be used in comparatively large quantities without causing injury to crops. Its use in greenhouses and for special purposes is fairly heavy, owing to its lasting qualities.

Bonemeal (steamed) is a product resulting from grinding animal bones that have been previously steamed under pressure. Steamed bonemeal contains less nitrogen than raw bonemeal, only about 2 percent on an average, but with an average higher content of phosphoric acid. In comparison with raw bonemeal the nitrogen and phosphoric acid of steamed bonemeal are more quickly available, owing to finer grinding of the latter and the removal of interfering fat. The nitrogen and phosphoric acid in bonemeal, whether raw or steamed, cost more than when bought in the form of inorganic nitrogen materials and superphosphate.

Precipitated bone is a byproduct obtained in the manufacture of glue stock from bones. It contains about 40 percent of available phosphoric acid chiefly in the form of dicalcium phosphate, the phosphoric acid of which, though not soluble in water, is soluble in neutral ammonium citrate. Precipitated bone phosphate is obtained by neutralizing the hydrochloric acid solution of processed bone with calcium hydroxide.

CALCINED PHOSPHATE

The term "calcined phosphate" refers to two products. One results from heating to a high temperature a mixture of ground phosphate rock with a compound of an alkali. This thermal treatment is claimed to render the phosphorus in the rock soluble in neutral ammonium citrate. The second product has been produced on a laboratory scale by heating ground phosphate rock, containing 5 to 10 percent of silica, in the presence of water vapor for 30 minutes at about 1,400° C. This effectively rids the rock of practically all its fluorine and renders the phosphorus in the resulting product available to crop plants. The phosphoric acid (P_2O_5) content averages about 34 percent, and when the treatment is effectively regulated it is soluble in neutral ammonium citrate solution. Tests made under greenhouse and field conditions show that these calcined phosphates rate highly as nutrient materials for different crop plants.

MONOPOTASSIUM PHOSPHATE

Monopotassium phosphate has considerable potential value as a fertilizer material if it can be produced on a commercial scale at a reasonable cost. It contains two nutrient elements, phosphorus and potassium, in an available form and would also be very adaptable to the preparation of concentrated fertilizers.

ROCK PHOSPHATE

Rock phosphate occurs in great deposits throughout the world, those of greatest commercial importance in the United States being located in Florida and Tennessee in the East, and in Idaho, Montana, Utah, and Wyoming in the West.

Besides the commercially recognized phosphate rock deposits in the United States, other deposits of importance occur in Nauru and Ocean Islands in the Pacific Ocean, in Morocco, Tunis, Algeria, and Egypt, and in the Union of Soviet Socialist Republics. On numerous other islands in the Pacific phosphate deposits have been located, but these have not always warranted commercial exploitation. Commercial utilization of phosphate rock deposits was first made in South Carolina in 1867–68, and for a number of years most of the phosphate rock utilized for the manufacture of superphosphate came from these deposits. The South Carolina deposits are now of no importance from a commercial standpoint and the heaviest production is in Florida and Tennessee where deposits were discovered, respectively, in 1888 and 1894. In the West there has gradually developed a demand for phosphate rock which has been met by supplies from the Western States mentioned above.

While a certain quantity of finely ground rock phosphate is used for direct application to the soil, it is slight in comparison with the enormous quantity of rock converted into superphosphate by acid or other chemical treatment. There

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are, no doubt, certain soil conditions and farm practices that enable finely ground phosphate rock to give a good account of itself, but taken by and large most soils and crops require a more available source of phosphoric acid, such as superphosphate, ammonium phosphate, or other phosphatic material the phosphoric acid of which is either water- or citrate-soluble.

"Colloidal phosphate" is a trade name applied to a finely divided, comparatively low-grade rock phosphate or phosphatic clay. It is also designated "waste pond phosphate" for the reason that in the hydraulic operation involved in mining rock phosphate in Florida a considerable quantity of fine phosphatic material, virtually colloidal from a mechanical standpoint, is washed into ponds and settles out. When removed, following drainage and evaporation of the water, it contains a relatively high proportion of clay, so that the Colloidal phosphate usually contains only from 18 to 23 percent of phosphoric acid. On account of the presence of so much foreign material, principally clay, Colloidal phosphate is considered to be unsatisfactory for treatment with sulphuric acid. The claim is made for this material and others of a similar nature that not only is the phosphoric acid more quickly available than that of mechanically ground rock phosphate, but also that the content of minor elements in Colloidal phosphate makes it superior to its close relative, rock phosphate. These claims, while highly interesting, have failed of substantiation in a number of States, particularly so when a comparison of such materials with superphosphate is taken into consideration.

As a general rule the effectiveness of any rock phosphate material is dependent upon its degree of fineness, the quantity applied to the soil, and the reaction of the soil. It has been shown that the best response ensues when the soil possesses a relatively strong acid reaction.

SUPERPHOSPHATE

Superphosphate (16 to 20 percent available P_2O_5) is an important phosphatic fertilizer material made by treating ground phosphate rock with sulphuric acid in approximately equal proportions by weight, the acid usually having a strength of 52° to 55° B. The resulting product is a mixture of monocalcium phosphate and calcium sulphate practically in equal proportions. This acidulation of phosphate rock converts the relatively insoluble tricalcium phosphate into an available form—monocalcium phosphate. Ordinary superphosphate can be produced to contain as much as 20 percent of available phosphoric acid, largely by selecting high-grade raw phosphate rock and by careful supervision of the chemical operations involved.

Superphosphate ranks first among all phosphatic fertilizer materials with respect to quantity consumed for fertilizer use. While it still occupies a commanding position in this respect it is important to note that when it comes to the preparation of so-called concentrated fertilizers ordinary superphosphate is of less importance, for the reason that its phosphoric acid content is not great enough to permit its use in the preparation of fertilizer mixtures other than those of ordinary strength. The preparation of concentrated fertilizers requires phosphatic materials such as ammonium phosphate or treble superphosphate.

Superphosphate is used principally as a source of phosphoric acid in complete fertilizers; for direct application to certain crops, principally on grassland; for reinforcing stable manure; and as a direct fertilizer treatment for soil deficient in phosphorus but well supplied with available nitrogen and potassium. Applied to decidedly acid soils in sufficiently large quantities, superphosphate reacts with some of the elements associated with such an acid soil condition, chiefly aluminum, thereby relieving crops from the ill effects of any toxic tendency that might result from the presence of soluble aluminum compounds. As a rule, however, such treatment is prohibitive in cost, and the same objective may be more cheaply attained by the use of lime.

When superphosphate was first prepared in the United States the term "acid phosphate" was applied to it. This earlier terminology prejudiced many against the material for the reason that acid phosphate implied an acid-forming tendency. As a matter of fact experimental studies over long periods offer conclusive evidence that this is not so. If anything, the continued use of superphosphate tends to ameliorate acid soil conditions by throwing toxic compounds out of solution. For these reasons the term "acid phosphate" was discontinued a number of years ago.

Triple (or treble) superphosphate (40 to 48 percent available P_2O_5) is similar to ordinary superphosphate in appearance but differs from it in containing very little calcium sulphate, which, however, does not appear to lower the effectiveness of

triple superphosphate. It provides a material possessing high concentration in phosphoric acid (P_2O_5) and therefore is exceptionally well suited to the production of concentrated fertilizer mixtures. In the production of triple superphosphate liquid phosphoric acid is used instead of sulphuric acid.

Potassic Materials[10]

KAINITE

Kainite was orginally a natural product of the European potash mines and sold in its crude state. It was composed chiefly of muriate of potash and sulphate of magnesium with about 30 percent of common salt, or sodium chloride. Commercial kainite was guaranteed to contain 12.4 percent of potash (K_2O), although some grades ran as high as 14 percent. In the United States kainite found its greatest use in fertilizers for cotton, one of the chief fertilizer-consuming crops grown in this country. Owing to its high chlorine content it was an undesirable source of potash for certain crops, especially tobacco and potatoes. The "Kainit" occurring in the trade at the present time is no longer the natural mine product but is a semi-refined product of potash manufacture corresponding to the 20-percent manure salts mentioned below.

MANURE SALTS

Manure salts formerly included a number of potash fertilizer materials with high chlorine content. The percentage of potash varied, but ordinarily the two principal grades contained approximately 20 and 30 percent respectively. The term "manure salt" as it occurs in commerce is now restricted to the 25- to 30-percent product, the 20-percent product being now called Kainit, as above mentioned.

POTASSIUM CHLORIDE

Potassium chloride (muriate of potash) contains about 48 to 62 percent of potash (K_2O). This salt is produced abroad through the refinement of carnallite, a crude potash salt containing approximately 8 to 10 percent of K_2O. The crude carnallite is ground, dissolved in hot water, and purified to the point where it contains from 48 to 50 percent of K_2O. It is also obtained from the brines of certain salt lakes and from sylvinite, a mixture of potassium and sodium chlorides.

POTASSIUM SULPHATE

Sulphate of potash (commercial potassium sulphate) should contain not less than 48 percent of potash (K_2O), chiefly as sulphate, and not more than 2.5 percent of chlorine. While sulphate of potash occurs in the German and Alsatian potash mines to a limited extent, the commercial preparation of sulphate of potash for fertilizer use consists in treating muriate of potash with sulphate of magnesium to obtain sulphate of potash through double decomposition. Sulphate of potash runs appreciably higher in cost per ton than the muriate of potash of equivalent (K_2O) content.

SULPHATE OF POTASH-MAGNESIA

Sulphate of potash-magnesia contains about 25 to 27 percent of potash (K_2O) in the form of the sulphate and about the same percentage of magnesium sulphate. It is made either from kainite or from potassium chloride and magnesium sulphate. Owing to its low chlorine content, generally less than 2.5 percent, this material is useful when a low chlorine fertilizer material is desired or where a shortage of magnesium has been noted.

OTHER POTASH SOURCES

Other potash sources adaptable to fertilizer use include potassium carbonate, double carbonate of potash and magnesia, and potassium nitrate. Besides the important salt brines of Searles Lake in California and the extensive potash deposits discovered in New Mexico, a considerable number of potash sources exist in the United States, including cement mills, blast furnaces, lake brines other than those in California, residues from beet-sugar and molasses plants, wood ashes, tobacco byproducts, seaweed, greensand marl, and certain minerals such as alunite, leucite, potash feldspar, phonolite, and nepheline. These last, including

[10] Potassium nitrate is described under Nitrogen Materials, p. 510.

greensand marl, have not been found equal to the more available potash compounds, even when very finely ground.

Miscellaneous Materials

AGRICULTURAL SALT

Agricultural salt has received considerable attention as an indirect fertilizer material. It is chiefly common salt, and its reputed value is thought to lie in its solvent action on phosphatic and potassic compounds natural to soils. This use of salt is uncommon, since any effectiveness to be ascribed to it may be obtained from the sodium chloride contained in kainite or in other low-grade potash salts.

ARTIFICIAL MANURE

The demand for barnyard manure is so great and the price so high that considerable interest has been aroused concerning the practicability of utilizing some of the waste organic materials to be found on the farm with the idea of converting them through bacterial agencies and certain chemical treatments into artificial, or synthetic, manure. This interest has been particularly keen among grain, fruit, and truck farmers. Artificial manure is a product resulting from treatment of straw and other available plant material with certain fertilizer materials and the addition of water to keep the pile moist at all times. Bacteria do the rest. The straw or other organic material furnishes them a food supply and the added chemicals serve them as sources of energy to such an extent that the straw decomposes in a comparatively short time.[11]

It is stated that the organic material is converted into the artificial manure in from 3 to 4 months with a considerable shrinkage in the original pile and that the resulting product has the beneficial effects ascribed to well-decomposed barnyard manure. This method of making artificial manure—essentially humus—may have practical value on farms where straw or other organic material is available, particularly where the straw cannot be utilized as feed or litter. Artificial manure as produced by one of the foregoing methods furnishes a material apparently of considerable value to market gardeners, truck-crop farmers, and others who cannot readily obtain good barnyard or stall manure except at prohibitive cost.

COAL ASHES

While possessing practically no fertilizer value, coal ashes, when properly sifted and incorporated with heavy soils (clays and clay loams in particular), exercise a beneficial effect on physical condition through improvement of tilth and drainage. Indirectly, therefore, coal ashes may prove worth while in the amelioration of heavy soils around the home grounds and in small gardens.

COCOA-SHELL MEAL

Cocoa-shell meal is a product resulting from the grinding of cocoa shells and husks of the seeds, the meal averaging 2.5 percent of nitrogen, 0.75 to 1 percent of phosphoric acid, and 2.5 percent of potash. Walton and Gardiner (*451*) refer to two other cacao byproducts—cocoa press cake and solvent-extracted cocoa—that might well have potential value as fertilizer materials.

COMPOSTS

In addition to numerous commercial fertilizer materials and barnyard manures there are many miscellaneous materials capable of being processed or composted, or applied to the soil direct, which possess fertilizer value. These materials furnish not only organic matter but also a certain amount of nitrogen, phosphorus, potassium, and other elements. They include leaves, weeds, sweepings from the house and barn, moldy feeding stuffs, coffee grounds, kitchen waste, soot, sod, grass clippings, fruit and vegetable refuse, etc. All such materials have some fertilizer value. Leaves alone, when dry, are about twice as rich per pound in plant food as barnyard manure. Instead of burning or discarding these miscellaneous fertilizer materials it is advisable to gather them into some out-of-the-way place and make a compost pile.[12]

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[11] The process for making artificial manure was studied at the Rothamsted Experiment Station in England. The agricultural experiment stations in Iowa, Michigan, Missouri, and New York have also made a study of the utilization of straw in the production of artificial manure.

[12] For further details on composting see (*109*).

CRUSTACEAN MATERIALS

Crustacean materials, including the refuse of king crab, mussels, crab, and lobster, are useful as fertilizer materials. King crab is found extensively along the Atlantic coast and is used as a direct application to the soil, composted, or in commercial fertilizer mixtures after being dried and ground. In the latter condition the material contains from 8 to 12 percent of nitrogen, with a comparatively high availability. In the fresh state, the material decays quickly and has a nitrogen content of 2 to 2.5 percent.

Mussels also are plentiful in certain coastal sections. They have a nitrogen content of 0.8 to 0.9 percent (nearly twice that of manure), phosphoric acid 0.1 to 0.15 percent, potash practically the same, and lime about 16 percent. Thus the material is worth carting and applying to the soil. Crab and lobster shells and refuse, which can be obtained for the carting, have some fertilizer value. When dried the material contains from 3 to 4 percent of nitrogen, 2.5 to 3 percent of phosphoric acid, and upwards of 18 to 20 percent of lime. All such materials are of some value if they are obtainable cheaply enough.

GREENSAND MARL (GLAUCONITE)

The greensand marls of New Jersey, where large deposits occur, contain on the average 5 percent of potash (K_2O), 2.2 percent of phosphoric acid (P_2O_5), and 3 percent of lime, all of which are rated as being slowly available. Marls, including greensand marl, are usually classified as soil amendments. In some sections of the country heavy applications of greensand marl have been reported as giving good results; in other sections their use after experimental trials is not recommended. In a great many instances the results from the use of greensand marl are due to the improvement of the physical condition of soils rather than to fertilizer elements.

GUANO

Guano (natural) is a substance formerly found in great abundance on some seacoasts or islands frequented by sea birds and composed chiefly of their excrement and dead bodies. The term also refers to the excrement of bats living in caves.

Guano is comparatively rich in nitrogenous and phosphatic substances. The nitrogen is present largely as ammonium compounds and in organic form. The composition of natural guano is quite variable in accordance with the protection from rainfall afforded the deposits. Analyses show a nitrogen content ranging from as low as 0.5 percent to as high as 10 to 12 percent. The phosphoric acid (P_2O_5) content may run as low as 10 to 12 percent and as high as 20 to 25 percent.

GYPSUM

Gypsum (land plaster) is found in nature and consists of a hydrated calcium sulphate. At the present time, owing to the heavy use of ordinary superphosphate, one-half of the total weight of which is gypsum or closely related to it, gypsum itself is used only when it is considered to be effective for special crops or special soil conditions where a deficiency of sulphur has been reported. In most cases, however, when gypsum has been found to give good results, it is believed that this was due more to its indirect effect in liberating potash from unavailable potash compounds than to its direct effect as a plant food.

LIME

Lime is not, strictly speaking, a fertilizer material but a soil amendment applied to correct soil acidity, improve the physical condition of the soil, and promote bacterial activity. However, one of its functions is to supply calcium if this is deficient in the soil. The chief sources are: (1) Burnt lime (CaO), known as caustic lime, stone lime, etc.—the product resulting from the burning of limestone; (2) hydrated lime or slaked lime, produced by adding the proper amount of water to burnt lime; (3) ground limestone, the most common form of lime used in farming practice, its agronomic value depending on the content of carbonate of lime and how finely it has been ground; and (4) marl, a natural deposit consisting chiefly of calcium carbonate mixed with clay, sand, or organic material.

MUCK AND PEAT

Muck and peat, while used for soil-improvement purposes, particularly in recent years, hardly rate as fertilizer materials. Frequently they are too acid to be used unless adequately limed. Muck and peat are air dried, ground if

necessary, bagged, and offered for sale as a humus material. As a rule they serve a good purpose when used as absorbents in the barn or barnyard. In many cases the effect of muck and peat upon the physical condition of the soil is more valuable than the plant nutrients they contain, particularly as the latter are in unavailable forms.

SEAWEED

Another material about which much has been written is seaweed. It has been used as a fertilizer material for many years. As early as the fourth century reference was made to the use of seaweed by Palladius in Rome. In England during Queen Elizabeth's reign seaweed found considerable use, and according to a contemporary writer named Owens "thereof springeth good corn, especially barley." Seaweed has been aptly termed the "poor man's manure." The history of its agricultural uses may be traced in every country with a seacoast from ancient days to the present time.

It is recorded, too, that in the north of Ireland fishermen who also till the soil collect seaweed by hooking it up from considerable depths. Reports from Bermuda indicate that seaweed—sargassum weed from the Gulf Stream—is much used as fertilizer, especially for bananas, on account of the ease with which it can be applied as well as its abundance.

There are many different kinds of seaweed, and they vary in composition. As a rule they are lacking in phosphorus, are comparatively rich in potassium, and have approximately as much nitrogen as stable manure, although an occasional kind of seaweed will carry twice as much.

Generally speaking, seaweed ranks as a potash fertilizer material. During the World War the giant kelp groves of the Pacific Ocean were given serious consideration as a potential source of potash, inasmuch as the ash of these seaweeds contains as high as 30 percent of potash (K_2O). The cost of extraction was prohibitive when high-grade German and French potash salts were again available.

TOBACCO BYPRODUCTS

Tobacco stems and stalks are waste materials from harvesting and the manufacture of cigars and smoking and chewing tobacco. The stems are often ground and sold as a fertilizer material. They usually contain 2 to 3 percent of nitrogen, from 6 to 10 percent of potash (K_2O), and very little phosphoric acid. The nitrogen occurs in both the organic and nitrate forms, the latter as potassium nitrate. When obtainable locally such material, if well ground, provides a good source of nitrogen and potash in comparatively quickly available combinations.

WATER HYACINTH

The water hyacinth grows abundantly in fresh-water streams and lakes along the Gulf coast. It is rated as a weed pest in localities where it abounds inasmuch as it is very difficult to control, and even more so to eradicate. When practically free of moisture, it contains about 1 percent of nitrogen, 4 percent of potassium, and a small amount of phosphorus. Practical trials by vegetable growers in Florida some years ago indicated that this material was worth while for garden crops, especially cabbages, potatoes, and sweetpotatoes. Its use as a mulch has been favorably reported in citrus and tung tree groves.

The water hyacinth grows profusely in other parts of the world, including Africa, Asia, Europe, and South America. Everywhere it is considered to be a rank pest. The Government of Bengal, India, in attempting to control its spread, sponsored experimental studies to determine whether water hyacinth possessed any fertilizer value. The results of this investigation indicated the material did have potentialities for soil-improvement purposes.

WHALE TANKAGE

Whale tankage represents the dried and ground residue resulting from the rendering of whale meat to obtain the oil. This material finds its way into the fertilizer market as a source of nitrogen. It averages about 7 percent of nitrogen and about 3 percent of phosphoric acid.

WOOD AND OTHER ASHES

Wood ashes rate as a potash material with a comparatively high lime content, some phosphoric acid and magnesium, and small amounts of other elements—all of which are affected by leaching if the ashes are not protected from rain and

melting snow. The composition of wood ashes varies considerably, depending upon whether they are derived from softwood or hardwood and the amount of contamination with other materials. Unleached hardwood ashes contain upward of 6 percent of potash in the form of carbonate, 2 percent of phosphoric acid, and 30 percent of lime. The leaching action of rain may reduce the potash content to as low as 1 or 2 percent. In addition to the fertilizer value of the available potash they contain, both the potassium and the lime carbonate in wood ashes are beneficial on acid soils.

Other kinds of ashes are sometimes used as fertilizer materials. The supply of cotton-hull ashes is very limited at present. They result from the burning of cotton hulls as fuel in ginning and pressing operations. Their composition is quite variable, ranging from 10 to 45 percent of potash, an average content of about 7 percent of available phosphoric acid, and approximately 8 to 10 percent each of calcium and magnesium compounds. Corncob ashes may run as high as 35 to 40 percent of available potash, although the average content is nearer 12 to 14 percent. The main source of supply comes from grain elevators and milling plants when the corncobs are burned and disposed of for fertilizer purposes. Tanbark ashes are inferior to wood ashes, as a rule containing not over 2 percent of available potash. Lime-kiln ashes are obtained in connection with lime-kiln operations and are even poorer than tanbark ashes in potash (approximately 1.5 percent), but are richer in lime carbonate than other wood ashes, frequently containing as high as 85 to 90 percent of calcium and magnesium carbonate. Owing to their variability in composition, all such ashes should be purchased only upon a guaranteed analysis.

OTHER MISCELLANEOUS MATERIALS

There is a considerable array of miscellaneous materials that possess some fertilizer value. Their use in most cases is economical only locally, and their low plant-food content would hardly warrant hauling and distribution unless they were obtainable at practically no cost. In a publication by C. C. Fletcher (*109*) is given the percentage composition of a large number of miscellaneous materials that have some fertilizer value if properly utilized.

Residual Effect of Fertilizer Materials Upon Soil Reaction

That certain fertilizer materials exercise an influence upon soil reaction has been recognized for many years. Thus, basic slag was employed as an agricultural liming material in 1881, and it is probable that such use even preceded recognition of the value of the slag as a phosphatic fertilizer material. Again, the ability of commercial calcium cyanamide to neutralize soil acidity has been known from the time of its introduction into the fertilizer trade. These materials, however, are alkaline in character and exhibit their alkalinity to such an extent that basic slag is not used as a source of phosphorus in the preparation of mixed fertilizers, since it would cause the liberation of ammonia from ammonium sulphate and other ammoniacal nitrogenous materials, while calcium cyanamide is used only in limited quantities as a source of nitrogen, since greater quantities would cause reversion of the phosphoric acid of superphosphate to unavailable forms. That such materials should be effective in reducing soil acidity is to be expected.

It has been found that other materials, such as ammonium sulphate and sodium nitrate, which chemically are neutral salts and themselves exhibit no marked alkaline or acid character, also have an ultimate effect upon soil reaction. Since this is not shown immediately upon application to the soil but develops during the course of the utilization of the nutrient elements by the crops, it is termed "residual effect." It has been explained as caused by a preferential intake by the plants of certain elements over others. Thus, in the case of sodium nitrate the nitrogen as the acidic nitrate ion is utilized to a greater extent than the basic sodium ion, which is left to neutralize other acidic ions originally in the soil, so that the ultimate residual effect is a decreased acidity or increased alkalinity of the soil.

In the case of fertilizer materials the nitrogen of which undergoes nitrification, an additional factor is the conversion of this nitrogen into the acidic nitrate ion, which as it is formed neutralizes bases in the soil. Thus, in the case of ammonium sulphate, the basic ammonium ions are converted into acidic nitrate ions, and both these and the residual acidic sulphate ion neutralize bases so that the residual

effect is an increased acidity or decreased alkalinity of the soil. Nitrogen is therefore to be considered as an acidic element regardless of its form in the fertilizer material, whether ammoniacal, nitrate, organic, or amide.

The potash salts customarily used for fertilizer purposes have been found not to affect soil reaction materially, though wood ashes and potassium nitrate, neither of which finds extensive employment as a fertilizer material, cause a decrease in soil acidity. The results of long-continued plot tests have shown that superphosphate has no appreciable effect on soil reaction.

On the basis of the experimental results obtained when various fertilizer materials were employed in vegetation tests, W. H. Pierre (*300*) of the West Virginia Agricultural Experiment Station, drew the conclusion that the differences in the effects of fertilizers on soil reaction are due to differences in their acid-base balance, in that materials containing an excess of a basic element (potassium, sodium, calcium, or magnesium) over the acidic elements (nitrogen, phosphorus, sulphur, and chlorine) give rise to a reduction in soil acidity, whereas materials that have an excess of acidic over basic elements bring about increased soil acidity.

Table 8.—*Calculated equivalent acidities and basicities of nitrogenous fertilizer materials*

Fertilizer material	Equivalent acidity per unit of nitrogen	Equivalent basicity per unit of nitrogen	Fertilizer material	Equivalent acidity per unit of nitrogen	Equivalent basicity per unit of nitrogen
	Pounds calcium carbonate	*Pounds calcium carbonate*		*Pounds calcium carbonate*	*Pounds calcium carbonate*
Ammonium sulphate	107		Calcium nitrate (13 percent nitrogen)		36
Sodium nitrate		36	Cyanamid		54
Potassium nitrate		36	Ammonium sulphate-nitrate	72	
Nitrate of soda-potash		36	Calurea	22	
Urea	36		Anhydrous or aqua ammonia	36	
Cal-Nitro (20.5 percent nitrogen) [1]	1		Urea-ammonia liquors	36	
Calcium nitrate (15.5 percent nitrogen) [2]		28	Crude nitrogen solution	25	
			Nitrogen solution II	36	

[1] Contains 35 percent of calcium carbonate.
[2] Contains 5 percent of ammonium nitrate.

Table 9.—*Equivalent acidities and basicities of nitrogenous fertilizer materials*

Fertilizer material	Nitrogen content	Equivalent acidity per unit of nitrogen	Equivalent basicity per unit of nitrogen	Fertilizer material	Nitrogen content	Equivalent acidity per unit of nitrogen	Equivalent basicity per unit of nitrogen
	Percent	*Pounds calcium carbonate*	*Pounds calcium carbonate*		*Percent*	*Pounds calcium carbonate*	*Pounds calcium carbonate*
Ammo-Phos	11	100		Tobacco stems	2.77		86
Do.	16.5	108		Do.	1.40		356
Animal tankage	9.12	3		Dried blood	13.00	35	
Garbage tankage	2.5		54	Do.	13.41	35	
Process tankage	7.5	31		Cocoa-shell meal	2.75		12
Fish scrap	9.25	18		Castor pomace	4.77	18	
Do.	8.93	2		Milorganite (an activated sewage sludge)	7.0	34	
Cottonseed meal	6.76	29					
Do.	6.71	28					

If, therefore, the amounts of each of these elements in a fertilizer material have been determined, the residual effect of the material should be capable of calcula-

tion. The results of such calculations are customarily expressed as equivalent acidities or equivalent basicities—that is, as the quantities of calcium carbonate (pure limestone) required to neutralize the acidity that would result from the use of residual-acid materials or that are equivalent in acid-neutralizing power to the residual-base materials. Table 8 lists the calculated values for a number of nitrogenous fertilizer materials.

For the determination of the equivalent acidities and basicities of fertilizer materials or mixtures without the necessity of chemical analyses to ascertain the quantities of each of the acidic and basic elements, Pierre (*301*) devised a chemical method that gave results in agreement with those obtained by calculation for materials of known composition. Since a description of this method in detail is decidedly technical in character, it will not be given here. By means of the method, Pierre obtained the results listed in table 9.

TWO-THIRDS *of the commercial fertilizers sold in the United States are in the form of mixtures rather than separate materials, and most of the mixtures contain all three of the principal fertilizer elements. This article tells how the commercial mixtures are made; describes the mixtures with high analysis and low analysis; discusses the important physical properties that a good mixture should have; deals with both good and bad effects of fertilizers on plants; and tells the farmer how he may reduce his fertilizer costs.*

Mixed Fertilizers

By William H. Ross *and* Arnon L. Mehring [1]

THE principal constituents of a fertilizer that give it commercial value are nitrogen, phosphoric acid, and potash. Most fertilizer materials contain only one of these constituents, but two or even all three may be found in a few of the fertilizer materials that are now on the market. The proportion in which the plant-food elements occur in any multiple-constituent material, however, is usually not best adapted for most soil requirements, and the needs of the plant as a rule are most economically supplied by applying a mixture of two or more materials.

The same agronomic results can be obtained by applying the materials to the soil separately as by mixing and distributing in the field in one operation, but the use of mixed fertilizers offers the following advantages: (1) The cost of applying a mixture is less than that of applying its various components separately; (2) mixtures, as a rule, are more drillable than many fertilizer materials; (3) the physiological acidity of fertilizers can be more conveniently and effectively controlled by the use of the proper amount of a liming material in a mixture than by its separate application in the field; and (4) the use of mixed fertilizers requires less care on the part of the farmer to insure a proper proportion of the plant-food elements in the soil than when individual materials are applied separately. These advantages do not hold, however, if a soil requires only one plant-food element.

The total consumption of all fertilizers in this country amounted to 8,204,000 tons in 1937. Of this total consumption about 67 percent was in the form of commercial mixtures and 33 percent in the form of separate materials or home mixtures (*250*).[2]

[1] William H. Ross is Senior Chemist, and Arnon L. Mehring, Associate Chemist in the Fertilizer Research Division, Bureau of Chemistry and Soils.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Mixed goods containing all three of the commercial fertilizing elements constitute the bulk of the fertilizers produced in the United States and are known as complete mixtures. Some mixed fertilizers contain only two of the fertilizing elements and are called incomplete mixtures. The most commonly used incomplete mixtures contain phosphoric acid and potash but no nitrogen. The phosphoric acid-potash mixtures amount to about 4 percent of all mixed fertilizers, the nitrogen-phosphoric acid mixtures to 0.3 percent, and the nitrogen-potash mixtures to only 0.1 percent.

CHANGES IN PLANT-FOOD CONTENT OF FERTILIZERS

Sir John Lawes (fig. 1) by developing and patenting a process for making superphosphate founded the commercial fertilizer industry in 1843. Statistics on the composition of complete fertilizer mixtures in this country date back to about 1880 (*250*). The changes that have taken place in the composition and plant-food content of fertilizer mixtures since that time are shown by the formulas given below:

Period and formula	*Pounds per ton*
1880 (2-9-2):	
Superphosphate, 12.5 percent P_2O_5	1,053
Fish scrap, 6 percent N; 8 percent P_2O_5	600
Nitrate of soda, 15.5 percent N	27
Kainite, 12.5 percent K_2O	320
Total	2,000
1910 (3-9-3):	
Superphosphate, 16 percent P_2O_5	1,125
Sulphate of ammonia, 20 percent N	100
Nitrate of soda, 15.5 percent N	130
Cottonseed meal, 7 percent N	285
Manure salts, 20 percent K_2O	300
1910 (3-9-3)—Continued.	
Filler	60
Total	2,000
1937 (4-9-5):	
Superphosphate, 19 percent P_2O_5	947
Ammonia, 2.3 percent of superphosphate	21
Urea, 46.6 percent N	18
Sulphate of ammonia, 20.5 percent N	166
Nitrate of soda, 16 percent N	63
Tankage, 7 percent N	170
Potassium chloride, 60 percent K_2O	166
Dolomite	224
Filler	225
Total	2,000

Table 1.—***Variation in the plant-food content of complete fertilizer mixtures***

Year	N	P_2O_5	K_2O	Total	Year	N	P_2O_5	K_2O	Total
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
1880	2.3	8.9	2.2	13.4	1929	3.1	9.8	4.6	17.5
1890	2.3	9.2	2.4	13.9	1930	3.2	9.7	4.9	17.8
1900	2.0	9.2	2.9	14.1	1931	3.3	9.6	5.0	17.9
1910	2.2	9.0	3.7	14.9	1932	3.4	9.5	5.1	18.0
1920	2.2	8.9	2.8	13.9	1933	3.5	9.3	5.2	18.0
1925	2.6	9.3	4.1	16.0	1934	3.6	9.2	5.3	18.1
1926	2.7	9.5	4.3	16.5	1935	3.6	9.1	5.4	18.3
1927	2.8	9.4	4.4	16.6	1936	3.8	9.3	5.5	18.5
1928	2.9	9.6	4.5	17.0					

These formulas are typical of the fertilizer mixtures in use in 1880, at the present time, and at the intermediate period of 1910. In 1880 organic nitrogen was the cheapest form of nitrogen, and the consumption of the organic ammoniates therefore exceeded that of any other source of nitrogen. At the present time these conditions are reversed. The typical mixtures of 1910 contained about equal quantities of ammonia, nitrate, and organic nitrogen. Present-day mixtures also differ from those of 1880 and 1910 in that they may contain a fourth form of nitrogen (amide nitrogen) as cyanamide or urea. The ammonia, nitrate, organic, and amide nitrogen in the 4–9–5 mixture represented above amount to 2.5, 0.5, 0.6, and 0.4 percent, respectively.

FIGURE 1.—Sir John Lawes, founder of the commercial fertilizer industry.

The changes in the plant-food content of the average mixed fertilizer used in this country in different years since 1880 are represented in table 1, which shows that the mixed fertilizers consumed changed from an average content of 2.3 percent of nitrogen, 8.9 percent of available phosphoric acid, and 2.2 percent of potash in 1880 to 3.7 percent of nitrogen, 9.3 percent of available phosphoric acid, and 5.5 percent of potash in 1936. The table also shows that the available phosphoric acid content of mixed fertilizers has changed little since 1880, while their nitrogen content has increased 61 percent and their potash content 150 percent.

The mixtures used in the early history of the industry contained a predominance of phosphate. The inconsistent practice in vogue of expressing the commercial plant-food elements as nitrogen, phosphoric acid, and potash gives the impression that the fertilizers used in this country still contain more phosphorus than nitrogen or potassium. If the values given in table 1 were expressed as nitrogen, phosphorus, and potassium, it would be found that the consumption in the United States in 1936 was about the same for all three elements.

MANUFACTURING METHODS

The manufacture of a mixed fertilizer is a very simple operation compared with the production of sulphuric acid or even of superphosphate. It consists in mixing suitable fertilizer materials in the right proportion to give the desired grade or analysis formula. The equipment used in different plants varies greatly. In the smaller plants it is limited to simple implements for hand labor, such as wheelbarrows, portable screens, and small mixing machines. The equipment in the larger plants consists of bins for holding materials and mixtures; electrically operated shovels, cars, and elevators for excavating the fertilizers and transporting them from place to place; mechanically driven crushing, grinding, screening, ammoniating, and mixing equipment (fig. 2); and

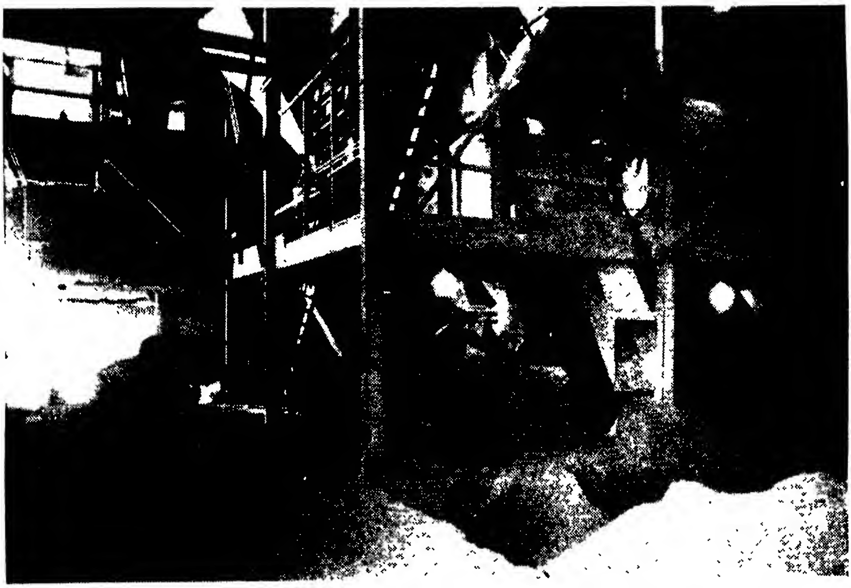

FIGURE 2.—Making mixed fertilizers in a modern factory. (Courtesy Davison Chemical Corporation.)

automatic machines for weighing the fertilizer, sewing the bags into which it is weighed (fig. 3), and loading the bags into freight cars.

In mixed fertilizer plants it is a common practice to prepare and keep in stock what is called dry base goods. This consists of a mixture of superphosphate and ammonium sulphate with or without other materials such as potash salts. The ammonium sulphate reacts with the superphosphate, and after the mixture has been allowed to stand for a time setting is likely to occur. When an order is received for a mixed fertilizer, the base goods are crushed, passed through a 5-mesh screen, mixed with a suitable proportion of other materials to give the desired grade, and finally placed in bags for shipment. All other ingredients are also crushed and screened before being included in the mixture. A mixed fertilizer prepared in this way is less likely to cake

in the bags than one containing superphosphate that had not been subjected to a curing treatment in mixture with ammonium sulphate.

The term "wet base goods" is applied to a product prepared by mixing phosphate rock with a waste nitrogenous material of low availability such as hair, leather, or feathers, and treating the mixture with sulphuric acid as in the manufacture of superphosphate. The chemical action of the sulphuric acid on the nitrogenous material converts the inactive nitrogen in whole or in part into an available form. The phosphate rock in the mixture neutralizes the sulphuric acid and gives a solid product that can be handled by fertilizer-mixing

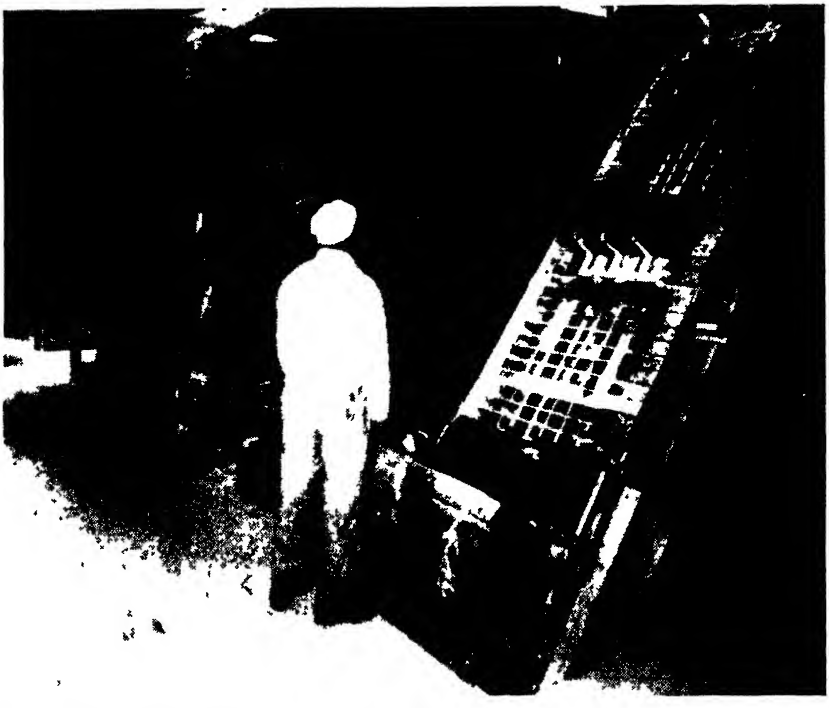

FIGURE 3.—Automatic bagging and handling of granulated fertilizer. (Courtesy Davison Chemical Corporation.)

machinery. During the past few years the manufacture of wet base goods in this country has greatly decreased.

AMMONIATION OF FERTILIZER MIXTURES

The first mixed fertilizers used in this country were prepared by mixing fish scrap or other nitrogenous material with bone superphosphate. To distinguish a mixture of this kind from a straight superphosphate, it was commonly referred to as an ammoniated superphosphate. Within the past few years this same term has been applied to a mixture of a somewhat different character prepared by treating superphosphate with free ammonia (*193*, *457*).

The treatment of superphosphate with a basic material such as

ground limestone, calcium cyanamide, etc., for the purpose of improving its mechanical condition is a practice of long standing in the fertilizer industry. The possibility of using free ammonia in the treatment of superphosphate was recognized many years ago, but its application for this purpose was not adopted until recently, owing to the relatively high cost of the ammonia. The cost of producing ammonia decreased rapidly following the improvements made in ammonia synthesis during and after the World War, and by 1926 free ammonia had become the cheapest form of fertilizer nitrogen (*250*). Its consumption in the ammoniation of superphosphate and superphosphate mixtures accordingly increased from about 5,000 tons in 1928 to about 36,000 tons in 1936. Its utilization in this way is one of the most interesting and important of the recent developments in the fertilizer industry.

The ammoniation of mixed fertilizers is a comparatively simple operation and usually consists in adding in successive batches a

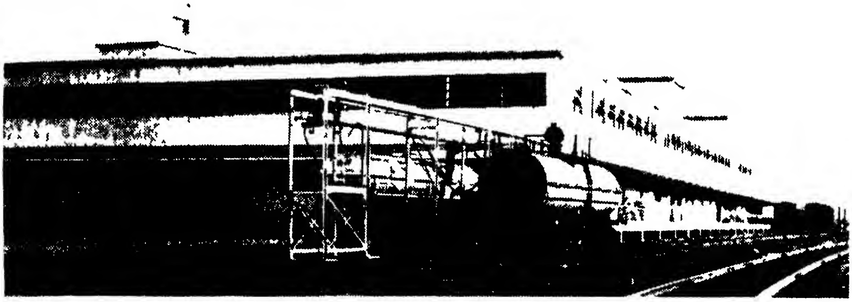

FIGURE 4.—A farmers' cooperative fertilizer-mixing plant showing tank cars of ammoniating liquors in foreground.

measured volume of anhydrous liquid ammonia, or a solution of ammonia, to a weighed quantity of the mixture in rotating drums or standard fertilizer mixers. Equipment has also been devised for carrying out the process in a continuous operation. An ordinary superphosphate will absorb a maximum of 8 to 9 percent of ammonia, but treatment with this quantity of ammonia decreases the availability of the superphosphate to plants (*320*). The quantity added in normal commercial practice is therefore limited to about 3 percent of the superphosphate. The absorption of this quantity of ammonia takes place very rapidly and the reaction is completed in less than a minute. A double superphosphate will absorb about three times as much ammonia as an ordinary superphosphate before serious reversion takes place.

The ammonia is shipped in steel tank cars (fig. 4). Solutions of ammonia in water have been used as well as anhydrous ammonia, but the former have been largely replaced by aqueous solutions containing dissolved salts in addition to ammonia. The compositions of these solutions are given in table 2. The solutions of ammonia do not exert as great a pressure as anhydrous ammonia; they can therefore be stored in cheaper containers, and the dissolved salts they contain can

be produced at a lower cost in solution than in the solid state. Anhydrous ammonia, on the other hand, gives a product that may be of superior mechanical properties.

Table 2.—*Composition of commercial ammonia solutions*

Component	Urea-ammonia liquor		Nitrogen solution		Component	Urea-ammonia liquor		Nitrogen solution	
	A	B	I	II		A	B	I	II
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*		*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
Free ammonia	29	19	45	20	Ammonium carbamate	18	21	-----	-----
Water	21	17	10	20	Sodium nitrate	----	---	45	-----
Urea	32	43		------	Ammonium nitrate	-----	----	-----	60

Treatment of superphosphate mixtures with ammonia is of economic importance for several reasons: (1) It is the cheapest form of nitrogen available to the fertilizer industry; (2) ammoniation greatly improves the mechanical condition and the drilling and storing qualities of superphosphate and mixed fertilizers containing superphosphate; (3) it greatly reduces the rotting of fertilizer bags; (4) it provides a means for the fixation of significant quantities of ammonia with minimum dilution of the superphosphate, which is of considerable importance for the use of ordinary superphosphate in the preparation of high-grade fertilizer mixtures; and (5) a considerable reduction in the quantity of sulphuric acid used in the manufacture of fertilizer materials may be effected by the substitution of free ammonia for ammonium sulphate as a source of nitrogen in mixed fertilizers.

HIGH- AND LOW-ANALYSIS MIXTURES

The raw materials used in preparing commercial fertilizers were obtained originally from two sources only—mineral deposits and industrial byproducts. The plant-food content of all these materials is relatively low and fertilizer mixtures prepared from them are necessarily low grade also. The mixtures used during the early history of the industry thus contained a low content of plant food for the very good reason that no economical methods were known at that time for preparing higher-analysis mixtures. During the first 50 years of the industry little change took place in the process of manufacture or in the plant-food content of the average mixed fertilizer.

Recent years have brought about a marked change. With the commercial development of nitrogen fixation a new and unlimited supply of materials became available to the fertilizer industry. These developments accompanied or were largely the result of the limitation of the available supply of organic nitrogenous materials. Many organic materials, such as cottonseed meal, dried blood, and animal tankage, which were once used largely in fertilizer mixtures, became more and more in demand as feeding stuffs and therefore relatively expensive. The synthetic products on the whole differ greatly in composition and properties from the organic materials which they are

required to supplement or replace. Some of the fixed-nitrogen products, such as sodium nitrate and ammonium sulphate, have essentially the same composition and properties as the same materials formerly obtained from other sources. Other fixed-nitrogen products, such as free ammonia, urea, ammonium nitrate, and ammonium phosphate, not only differ in their chemical and physical properties from any of the materials formerly used as fertilizers but contain a much higher proportion of the plant-food elements. When materials of this kind are used in mixed fertilizers it therefore becomes necessary to raise the grade of the mixture or to dilute it with sand or other filler if the grade is to remain the same.

The economic advantages to be gained in increasing the plant-food content of mixed fertilizers rather than in diluting the mixture with filler were first emphasized by the Bureau of Soils about 20 years ago (*323*). The view was advanced that the use of higher grade mixtures than those then in use would mean lower transportation, handling, bagging, and storage costs and thus make possible economies in the factory and on the farm.

The fixed-nitrogen products afforded a means for increasing the nitrogen content of fertilizers, and, with a view to reducing shipping costs, commercial methods were developed for increasing the concentration of potash salts by crystallization. The average mixed fertilizer in use at the time that the fixed-nitrogen products first came on the market contained about 50 percent more phosphoric acid (P_2O_5) than nitrogen and potash combined. An increase in the plant-food content of the phosphatic materials used in fertilizers would therefore have been more effective in raising the grade of the average fertilizer mixture than a corresponding increase in the carriers of either nitrogen or potash. It was for this reason that the Bureau of Soils undertook, about 20 years ago, an investigation of the electric-furnace method of producing phosphoric acid. By applying the method of electrical precipitation to the recovery of the volatilized acid, it became possible to produce directly acid of any desired concentration (*318*). When concentrated phosphoric acid is available it is a relatively simple matter to convert it into a high-analysis material, such as double superphosphate. This is made by treating finely ground phosphate rock with a suitable proportion of the acid.

The changes that have thus been made in fertilizer manufacture during the past few years have brought about a marked increase in the grade of the mixed fertilizers used in certain sections of the country, while in other sections the continuing demand for the same popular grades has resulted in an increased use of filler. The net result has been a 20-percent increase in the total plant-food content of the average mixed fertilizer and a 65-percent increase in the use of filler during the past 20 years. The range of the plant-food content of present-day mixtures is therefore much greater than that of the mixtures on the market a few years ago.

Numerous suggestions have been made for grouping fertilizers according to their plant-food content, but none has been adopted officially. The most commonly used classification divides fertilizers into three groups known as ordinary, high-analysis, and concentrated fertilizers. The first group includes all mixtures containing less than

20 percent of nitrogen, phosphoric acid, and potash; the second all those containing 20 percent and up to 30 percent; while the third group includes all fertilizers that contain 30 percent or more of total plant food. Although usage may lead to the permanent adoption of the terms employed in this classification of fertilizers, this is unfortunate for several reasons. They imply, for example, that the fertilizers belonging to the different groups are radically different from each other. This is not necessarily the case, as shown by the comparison of the formulas in table 3. The use of the term "concentrated" as applied to fertilizer materials and mixtures is open to the further objection that it gives rise to considerable misunderstanding as to the nature of the fertilizers belonging to this class. As applied to a fertilizer material, it should have reference only to the total plant-food content of the material and not to its purity or nondilution with other substances.

Table 3.—*Fertilizer formulas of single- and double-strength mixtures*

Component	Single-strength mixture (4-8-4)	Double-strength mixture (8-16-8)	Component	Single-strength mixture (4-8-4)	Double-strength mixture (8-16-8)
	Pounds	*Pounds*		*Pounds*	*Pounds*
Superphosphate	867	------	Tankage	115	230
Double superphosphate	------	666	Potassium chloride	133	266
Ammonia	24	48	Dolomite	176	352
Urea	34	68	Filler (sand)	466	------
Ammonium sulphate	122	244			
Sodium nitrate	63	126	Total	2,000	2,000

A more logical terminology for the three groups into which it has been proposed to divide fertilizers would be low-, medium-, and high-analysis fertilizers, but for the present this would also lead to misunderstanding, because the average total plant-food content of commercial fertilizers is still less than 19 percent and many fertilizer mixtures which are now considered as high grade in some localities would be placed by this classification in the low-grade group. There is also a tendency at present to classify fertilizers according to grade into two groups only, those containing up to 20 percent of total plant food being considered as ordinary or low-analysis mixtures while those that contain more than 20 percent are referred to as high-analysis mixtures.

Many of the most popular grades in use at the present time contain from 14 to 20 percent of plant food. Farmers find it more convenient to use a well-known fertilizer grade or multiple of this grade rather than grades with which they are not familiar. The plant-food content of many of the high-analysis mixtures that have recently come on the market is therefore exactly double that of a mixture that has been in use for many years. A mixture of this kind is referred to as a double-strength mixture and the corresponding low-analysis mixture as a single-strength mixture.

If low-analysis materials could be obtained in unlimited quantity near all points of consumption, there would perhaps be little economy

in the use of high-analysis mixtures, for it is recognized that the use of such materials may offer certain advantages which may be lacking in those of a highly concentrated nature: (1) Their use in fertilizers affords a market for low-grade byproducts which would otherwise be wastes in the industries; (2) the fertilizing constituents that they contain may vary greatly in availability and thus serve as a source of food supply for the plant during the entire growing season; (3) while some of their constituents, such as calcium, magnesium, and sulphur and the different forms of organic matter, add nothing to their commercial value as fertilizer in most States, they may nevertheless have a beneficial effect on many soils; (4) many low-grade materials have the property of improving the physical condition of the whole fertilizer mixture; and (5) with some types of distributing machinery small applications of plant food per acre can be made more conveniently in the form of low-grade than of very high-grade mixtures.

It happens, however, that the greatest increase in the use of fertilizers is now taking place in States that have a limited supply of many fertilizer materials, and the cost of handling and transporting low-analysis fertilizers is a very serious disadvantage to their use in such localities. The question of supply at reasonable prices is a still more serious objection to dependence on many low-grade materials for future expansion in fertilizer manufacture. A number of materials, such as cottonseed meal and fish scrap, which were once so largely used in fertilizers, can now be obtained only at a cost that largely offsets the advantages claimed for them. The use of the synthetic products in fertilizer mixtures therefore becomes necessary irrespective of their properties.

It fortunately happens, however, that recent developments in fertilizer manufacture, such as ammoniation, granulation, and the preparation of physiologically neutral mixtures have largely eliminated the difficulties that first attended the use of the fixed-nitrogen products in the preparation of high-analysis mixtures. That double-strength mixtures having essentially the same properties as the most popular single-strength mixtures can now be prepared is indicated by a comparison of the fertilizer formulas given in table 3.

The single-strength mixture represented in table 3 is used in more States and for a greater variety of crops than any other mixture. The mixture as formulated contains ammonia, nitrate, and organic nitrogen in the proportion in which they are commonly used at present, and sufficient dolomite has been included to make a physiologically neutral mixture. The filler in the mixture amounts to 23.3 percent, or 466 pounds per ton. If 400 pounds of this filler were omitted, the mixture would become a 5–10–5 mixture without any change whatever in its plant-food components. The second formula in the table gives the composition of a fertilizer mixture having exactly double the plant-food content of the 4–8–4 mixture. The formula of the double-strength, or 8–16–8, mixture differs from that of the 4–8–4 mixture only in that double superphosphate is substituted for ordinary superphosphate in addition to the elimination of filler. As all other components remain the same, the only essential difference in the composition of the two mixtures is that the double-strength mixture contains a lower content of calcium sulphate, a

component of ordinary superphosphate. The calcium content of the mixture, nevertheless, exceeds that of any other constituent and should be ample for all purposes. The percentage of sulphur (expressed as SO_3) in the mixture, notwithstanding the lower content of calcium sulphate, is approximately the same as that of either nitrogen or potash and also should meet all requirements. If this is assumed to be true, it may be concluded that a marked increase may be made in the plant-food content of many of the most widely used fertilizer mixtures without producing any appreciable change in their chemical, physical, or physiological properties.

PROPERTIES OF MIXED FERTILIZERS

The efficiency of a fertilizer depends (1) on the uniformity with which it can be distributed in the field, and (2) on its physiological quality or effect on crop yields.

Fertilizers cannot be uniformly distributed if they cake or become sticky, if they undergo segregation on handling, or if their drillability is poor for any other reason. A fertilizer is said to be of poor quality if it (1) causes injury to plants when applied in the usual way; (2) increases unduly the acidity of the soil; or (3) contains an unbalanced proportion of the fertilizing elements. The uniformity of distribution of a fertilizer is thus dependent on its physical properties and its quality on its chemical composition.

Drillability

Caking is a property of fertilizers with which farmers have so long been familiar that it is often taken as a matter of course. This condition involves extra labor and interferes with the uniform distribution of a fertilizer in the field. If the distribution of a fertilizer is irregular, some plants may be injured by an excessive application while others may be insufficiently fertilized for best results. The drillability of a fertilizer is therefore a very important factor in determining its efficiency.

The principal factors that determine the drillability of a fertilizer are its moisture content and its state of subdivision. All soluble substances have the property of absorbing moisture from the air when the humidity reaches a value that is characteristic for each substance. It thus happens that some materials will absorb moisture from the air at ordinary humidities. They are said to be hygroscopic. Other materials that take up moisture from the air only when the humidity is in excess of that which ordinarily prevails are said to be nonhygroscopic. Measurements of the hygroscopicities of the most common fertilizer salts, singly and in pairs, have been made by the Bureau of Chemistry and Soils (*254*). The data obtained may be used as a guide in preparing mixtures of good physical condition or in predicting the relative hygroscopicities of different combinations of fertilizer materials.

Many low-analysis materials such as superphosphate and the organic ammoniates are nonhygroscopic, but other materials of this kind such as calcium nitrate and sodium nitrate are among the most hygroscopic of fertilizer materials. In the same way, some high-analysis materials, like ammonium nitrate and urea, absorb moisture from

the air very readily, but other high-analysis products such as ammonium phosphate, potassium nitrate, potassium sulphate, and double superphosphate are among the least hygroscopic of known soluble salts. There is thus no correlation between the plant-food content of a fertilizer and its hygroscopic properties.

The presence of moisture in a fertilizer or its absorption from the air may induce a caked or a sticky condition in a fertilizer (1) by causing it to set like plaster of paris; (2) by forming a thin liquid layer over the surface of each soluble particle; or (3) by causing the crystals to knit together as the humidity alternately rises and falls or the material undergoes changes in temperature.

A dry nonhygroscopic material does not set by absorption of water from the air, but setting may occur if moisture is present. When setting is complete no further action takes place and the original condition of the material may be restored by grinding. This treatment, however, has no permanent effect in improving the mechanical condition of hygroscopic materials. When the humidity is high such materials absorb moisture from the air and a portion of the material goes into solution to crystallize out again when the humidity drops. Changes in temperature may produce the same effect without a change in humidity. When the temperature rises an increased portion of the salt may dissolve in the moisture already present and crystallize out again when the temperature falls. This may cause the crystals to knit together to such an extent that the material may cake into a solid mass (*324*).

Segregation

A second property that interferes with the uniform distribution of a fertilizer is segregation. The ordinary types of complete fertilizers consist of mixtures of a number of materials having different specific gravities, and the size and shape of their particles are also different. When a mixture of this kind is poured, as in filling sacks or distributors, the largest, heaviest, and most symmetrical particles fall fastest and after landing in a heap roll farthest, thus tending to accumulate at the bottom and the outer edges of the pile (*252*). A fertilizer immediately after being poured is in a loose condition, but if this loose mass is jarred or shaken, as when a distributor containing it is hauled over a field, settling occurs by rearrangement of the particles in a tighter packing. In the process of settling the powdered materials sift down and gradually pack the spaces between the larger particles. If each component of the mixture consists of about the same range of sizes, this has little or no effect on composition; but if one component is composed of large granules while another is more or less pulverized, serious segregation may take place. As a result of this separation the mixture ceases to be uniform throughout and when it is applied in the field different plants do not receive the same relative amounts of the different fertilizing elements. The change in uniformity of composition as a result of segregation has the further disadvantage that it increases the difficulty of obtaining representative samples for control work and of determining the true grade of a fertilizer mixture.

Granulation

To overcome segregation and improve the drillability of fertilizer mixtures, a treatment has been developed known as granulation. This consists in converting the mixture into granules of uniform size that contain the components of the mixture in approximately the same relative proportion. Segregation and loss by blowing on windy days are thereby prevented and the tendency of the mixture to cake or become sticky is reduced.

Soluble materials which show little tendency to absorb moisture from the air are usually of good mechanical condition, but some of these materials have the characteristic property of caking to a solid mass even when their moisture content is relatively low. Caking of such materials may be easily and permanently prevented by mixing with a powdered insoluble material such as tankage or cottonseed meal. The fine particles of insoluble material adhere to and form a coating over the more sticky surfaces of the soluble particles. This coating largely eliminates stickiness and greatly improves the mechanical condition of the mixture.

The organic ammoniates thus serve the double purpose of supplying nitrogen and of acting as conditioners in fertilizer mixtures. If such materials were available at prices that would permit of their liberal use there would be less need of developing granulating methods for improving the mechanical condition of fertilizers. The present cost of these materials, however, limits their use as fertilizers. Mixtures of good mechanical condition may be prepared without the use of organic conditioners by proper selection of their components and by ammoniating the mixture, but granulation affords the most generally effective method for improving the physical properties of a fertilizer mixture.

The first work on the granulation of fertilizers was undertaken in the Bureau of Soils in 1922. A number of the synthetic products are readily fusible, and it was found that they could be converted into a granular form by heating the material to a temperature just above the melting point and spraying the molten product into the top of a tower through which a stream of air is passed in an upward direction. The sprayed molten particles congeal in their fall through the tower to form spherical particles of uniform size and shape (*85*). This method has since been developed commercially for the granulation of such materials as urea, Calurea, Cal-Nitro, and sodium nitrate.

Granulated materials have become very popular for separate application in the field, but the use of such materials in fertilizer mixtures promotes segregation unless all the components of the mixture have the same sized particles. The separate granulation of all the materials in a mixture would add greatly to the cost. A great deal of attention has accordingly been given of late to methods for the granulation of complete mixtures in one operation. The method which gives most promise of commercial application is known as granulating by rotary drying. This method, as developed by the Fertilizer Research Division of the Bureau of Chemistry and Soils, consists in adjusting the moisture content of the mixture, if necessary, by the addition of water or steam, to the optimum for granulation, raising the temperature to 60° to 80° C. by ammoniation or otherwise, rolling in a drum until

granulation takes place, and drying the granulated product in a rotary drier (*319*).

Granulation occurs when a powdered material or mixture is rolled or tumbled while in a semiplastic condition. Although this condition may be induced at normal temperatures in some mixtures by simply increasing the moisture content, better results are obtained with less moisture when the temperature is increased to that normally obtained by ammoniation (*142*). The conditions under which granulation is obtained vary greatly in different mixtures. Conditions of temperature and moisture that would be insufficient to produce granulation in some mixtures will give a puddled or semifluid mass in others.

Mixtures that consist largely of inorganic materials granulate more readily and with a lower moisture content than those that are relatively high in organic matter. A double-strength mixture has only half the bulk of a single-strength mixture per unit of plant food, and other conditions being the same should cost only half as much to granulate. Granulation would seem, therefore, to be adapted particularly to the treatment of high-analysis mixtures that are low in or free from organic components. Such mixtures are usually those most likely to be benefited by any treatment for the improvement of drillability.

Injury to Crops

Seedling injury or crop burning occurs when the soil solution in contact with the roots of the plant contains too high a concentration of one or more soluble salts. Some salts are toxic to plants at relatively low concentrations and produce crop burning by interfering with the metabolism of the plant. Other salts are less toxic to plants and give rise to crop burning only when a sufficient quantity is present to develop an osmotic pressure in the soil solution that is greater than that of the plant sap. The plant, no longer able to absorb moisture through its roots, withers and dies. This effect on plants is not characteristic of fertilizers alone but may be caused by all readily soluble salts. Thus, sodium chloride, or common salt, which contains none of the primary fertilizing elements, will prevent germination or burn crops as readily as potassium chloride, which contains upwards of 60 percent of plant food.

In the early history of the industry many fertilizers were largely composed of slightly soluble materials or of insoluble materials that as a result of chemical changes slowly yielded soluble substances. Mixtures of this kind could be applied to the soil with little or no danger of increasing the concentration of the soil solution to a point that would be injurious to plants. At a later date the salt content of mixed fertilizers was greatly increased by the increased use of sodium nitrate and low-grade potash salts. In recent years a still further change has taken place in the composition of fertilizers. The slowly soluble materials have been largely replaced by the fixed-nitrogen products, all of which are readily soluble in the soil solution. Unless steps had been taken to correct the situation, there would have been more danger of burning in the use of the present-day mixtures than of those formerly on the market. The steps that have been taken consist in (1) increasing the plant-food content of the mixture so that less fertilizer has to be distributed per acre for a given application of the

plant-food elements; (2) replacing kainite and other low-grade potash salts with high-grade muriate; and (3) substituting in part free ammonia and urea for sodium nitrate and other readily soluble salts.

At one time kainite containing only 12 to 16 percent of potash was the principal potash salt used in fertilizer mixtures. This material contained a large proportion of sodium chloride and other readily soluble nonfertilizing components. If these components in a fertilizer mixture are replaced by an equivalent quantity of the fixed-nitrogen products, the effective soluble salt content of the mixture will remain the same as before and no change will be made in the burning effect. This is now what is actually being done. The K_2O content of the potash salts used in mixed fertilizers increased from an average of 20 percent in 1905 to 48 percent in 1936.

The extent to which different fertilizers increase the concentration of the soil solution has recently been studied in the Bureau of Chemistry and Soils (*458*). It was found that the change in the concentration of the soil solution as a result of fertilizer treatment varies greatly with different soils but that the relative effects of the different fertilizers remain the same. Thus, superphosphate and free ammonia have the least effect on the salt content of the soil solution for equal applications of plant food, while sodium nitrate and low-grade potash salts have the greatest effect.

The tests further demonstrated that a mixture typical of that in use 15 or 20 years ago, containing potash in the form of low-grade kainite or manure salts, increased the concentration of the soil solution to a greater extent than a mixture of the same grade formulated from present-day materials. This relationship also held true when the nitrogen content of the present-day mixture was doubled. The results indicate that danger from salt injury in the use of typical present-day mixtures is less than for those formerly used even when the nitrogen in the older type mixtures is applied to the crop in split applications.

When equivalent quantities of single- and double-strength mixtures are applied per acre, the effect of the single-strength mixture on the concentration of the soil solution may be greater or less than that of the double-strength mixture, depending on the nature and solubility of the materials used in the mixtures (*458*). Thus a double-strength mixture which consists entirely of soluble salts may have a greater effect in increasing the concentration of the soil solution than a single-strength mixture of relatively low solubility. Numerous tests have shown, however, that when double-strength and single-strength mixtures are prepared as in present commercial practice the danger from injury in the use of the former will be less than in the case of the latter, inasmuch as only half as much of the double-strength mixture per acre is required to give an equal application of plant food.

Influence of Mixed Fertilizers on Soil Reaction

In the early history of the industry the principal nitrogenous materials used in mixed fertilizers were fish scrap and sodium nitrate. This combination had a basic or alkaline influence on the soil (p. 520) and the mixtures containing them were likewise basic. With increase in the use of ammonium sulphate the average mixture became less

basic (table 4). In 1906, it was neutral. Then it became more and more acid, until it reached a maximum acidity equivalent to 148.5 pounds of calcium carbonate per ton in 1932 (*249*). It then became generally recognized that the use of such acid-forming fertilizers would in time bring about a marked decrease in the crop-producing capacity of the soils to which they were applied. To offset this effect the practice was developed of including in fertilizer mixtures a sufficient quantity of a basic material to counteract its acid influence on the soil. Dolomite was found to be superior to limestone for this purpose, as it serves as a source of magnesium as well as of calcium and does not cause a loss at normal temperatures of available plant food in mixtures of the ordinary type (*30*).

Table 4.—*Variation in the influence of fertilizers on the soil reaction*

Year	Ammonium salts	Nitrates	Organic ammoniates	Cyanamid and urea	Equivalent quantity of limestone per ton: Basicity	Equivalent quantity of limestone per ton: Acidity
	Percent	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*
1880	0.18	0.09	2.03		40.8	
1885	.42	.12	1.86		11.5	
1890	.31	.18	1.84		16.1	
1895	.18	.13	1.79		39.2	
1900	.12	.19	1.48		38.8	
1905	.22	.51	1.10		23.9	
1907	.47	.43	1.25			14.8
1910	.60	.42	1.26			31.4
1915	.53	.50	1.06	0.07		22.0
1920	.51	.65	.82	.19		15.4
1921	.65	.56	.81	.22		28.8
1922	.78	.63	.82	.22		40.0
1923	.78	.57	.89	.23		41.8
1924	.81	.69	.97	.24		39.4
1925	1.06	.61	.86	.25		70.3
1926	1.14	.53	.99	.26		81.2
1927	1.50	.38	.79	.27		127.4
1928	1.55	.40	.77	.28		130.6
1929	1.59	.46	.70	.35		124.2
1930	1.80	.42	.81	.26		141.8
1931	1.93	.39	.79	.25		146.9
1932	2.09	.52	.68	.42		148.5
1934	2.32	.33	.72	.27		105.0

The acidity or basicity of a mixture of known composition and the quantity of dolomite required to make it physiologically neutral may be easily calculated from the data given on page 520 for the equivalent acidity and basicity of fertilizer materials. Thus the materials in the 4–9–5 mixture that determine its influence on the soil reaction (table 5) are ammonia, ammonium sulphate, urea, sodium nitrate, and cottonseed meal. The acidity or basicity of these materials, the units of nitrogen used in a ton of the mixture from each material, and the total acidity or basicity of each material per ton of the mixture are given in table 5.

The last two columns of table 5 show that the acidity of the acid materials in the 4–9–5 mixture exceeds the basicity of the basic material present by the equivalent of 242−18=224 pounds of limestone. This quantity of limestone, or preferably the equivalent quantity of dolomite, must therefore be added to the mixture to make it physiologically neutral in reaction.

BALANCED FERTILIZERS

Soils differ greatly in their content of the essential plant-food elements, and the proportion of the mineral elements required by different crops also varies greatly. With a view to supplying deficiencies in the soil and meeting the requirements of different crops, mixed fertilizers are being prepared in many different grades. The grade of a fertilizer refers to its percentage content of the primary plant-food constituents, nitrogen, phosphoric acid, and potash. These different grades have been increasing in number throughout the history of the industry until at present fully 1,000 grades are being sold in different parts of the country. Of this number, about one-third were reported for 1934 (*251*) from Florida alone, although this State consumes less than 6 percent of the total fertilizer tonnage. Alabama, with a slightly higher tonnage, used only 56 grades, and Mississippi 21 grades. In the great majority of States one-fourth or more of the total tonnage is represented by a single grade, and more than 50 percent of the tonnage by three or four grades. Even in Florida about half of the total tonnage was accounted for by a dozen grades and one-half of the grades accounted for less than 25 tons of fertilizer each. The use of small tonnages of so many grades adds greatly to the cost of manufacture and a campaign has been undertaken in a number of States for the elimination of unnecessary fertilizer grades.

Table 5.—*Nitrogen content and equivalent acidity of a 4–9–5 mixture*

Material	Nitrogen content		Reaction per unit of nitrogen		Units of nitrogen per ton of mixture	Total equivalent quantity of limestone per ton	
			Acidity	Basicity		Acidity	Basicity
	Percent	*Pounds*				*Pounds*	*Pounds*
Ammonia	83.2	21	36		0.8	29	
Ammonium sulphate	20.5	166	107		1.7	182	
Urea	46.6	18	36		.4	14	
Sodium nitrate	16.0	63		36	.5		18
Cottonseed meal	7.0	170	28		.6	17	
Total						212	18
Net equivalent acidity						224	

Definite action on the standardization of fertilizer grades is taken annually by the States of Arkansas, Louisiana, Mississippi, Oklahoma, and Texas at joint conferences held between the State agricultural officials and the fertilizer manufacturers doing business in these States. At these conferences an official list of grades is selected for the coming fertilizer year. The use of the adopted grades is enforced by refusing registration for other grades. It is claimed that standardization of grades helps the farmer to become familiar with the different kinds of fertilizer and to decide more readily on the proper kind to use, enables the agricultural worker to make definite recommendations, and reduces the cost of manufacture and handling.

The agricultural experiment stations of the Middle Western, Middle Atlantic, and New England States acting in groups have also recommended the use of a limited number of fertilizer grades, but no action has been taken to enforce the use of the recommended grades.

The principal fertilizer grades applied to five of the most frequently fertilized crops in the States consuming 75 percent of the total fertilizer tonnage are given in table 6.

Table 6.—***Most commonly used grades for principal fertilized crops in States consuming 75 percent of the total fertilizer tonnage***

State	Cotton		Corn		Potatoes		Wheat		Tobacco	
	Grade	Application per acre	Grade	Application per acre	Grade	Application per acre	Grade	Application per acre	Grade	Application per acre
		Pounds		*Pounds*		*Pounds*		*Pounds*		*Pounds*
Alabama	6-8-4	300	3-8-5	100	4-10-7	1,000	-------	-------	-------	-------
Florida	3-8-5	300	4-8-4	200	4-8-8	2,000	-------	-------	3-8-5	1,000
Georgia	4-8-4	350	3-9-3	200		-	2 10-4	200	3-8-5	1,000
Indiana	-------	-------	2-12-6	125	0-10-10	500	2-12-6	125	2-12-6	200
Maryland	-------	-------	2 12-4	100	6-6-5	2,000	2 8 5	250	4-8-12	800
Mississippi	4-8-4	300	4-8-4	150	6-10-7	1,000	-------	-------	-------	-------
North Carolina	3-8-3	400	3-8-3	200	6-6-5	2,000	3 8 3	200	3-8-5	1,000
New York	-------	-------	4 12-4	300	4-8-7	2,000	2-8-10	250	-------	-------
Ohio	-------	-------	2-12-6	125	4-8 8	1,000	2-12-6	200	4-10-6	400
Pennsylvania	-------	-------	2 8-5	200	2-8 10	1,000	3-12-6	250	4 8-7	750
South Carolina	3 8 3	400	3 8 3	200	6-6-5	2,000	3-8-3	200	3 8-5	600
Virginia	0-10-4	400	3-8-3	200	6-6-5	2,000	0-16-0	300	3-10-6	1,000
Louisiana	4-8-4	200	-------	-------	4-12-4	800	-------	-------	-------	-------
Maine	-------	-------	3-10-6	600	4-8-10	2,000	-------	-------	-------	-------

A variation in the grade of a fertilizer is designed chiefly to adjust the proportions of the primary fertilizer elements in the soil. It is now recognized that the efficiency of a fertilizer depends also on its content of other plant-food elements, such as calcium, magnesium, and sulphur as well as nitrogen, phosphorus, and potassium (*470*). It is possible therefore that the proportion of these minor elements in a fertilizer mixture may also have an important part in determining the efficiency of fertilizers.

It is well known that crops grown on different soils differ greatly not only in yields but also in quality, appearance, and resistance to spoilage. The flavor of many fruits and the quality of tobacco and other crops grown in certain parts of the country are far superior to the best that can be produced in other localities. In certain parts of the country there are small areas of land that have a capacity for producing crops that far exceeds that of other localities irrespective of the manner in which the soil is fertilized or otherwise treated. It is recognized that climate and water relations have a great deal to do with the fertility of a soil, but even when due allowance is made for these factors, soils may still differ greatly in the yield and quality of the crops they produce. The view has been advanced that highly fertile soils may differ from those that are less productive in that they contain the proper balance of all the essential plant-food elements for maximum growth without any excess or deficiency of any mineral constituent.

At present there is no way of determining how far a soil falls short of containing this optimum balance, but as further information is gained in this field it is possible that fertilizers will be formulated so that the grade will have reference to the proportion of the secondary as well as of the primary elements in the mixture.

FERTILIZER ECONOMICS

Much progress has been made in the past in developing cheaper sources of fertilizer materials and new and cheaper methods of fertilizer manufacture. As a result of discoveries and improvements, the 1936 mean wholesale f. o. b. price of all fertilizer materials, except the organic ammoniates, was only about one-half of what it was in 1900 (*248*). It is only reasonable to expect that further research in fertilizer technology will reduce manufacturing costs still more, but in order to reduce them as much in the future as in the past it would be necessary to produce them at no cost, and this is clearly impossible.

If the cost of production of every material used in fertilizer mixtures were cut in half again and the total possible savings were passed on to the consumer, the farmer would save only 17 percent of his bill for fertilizer. This is because of the many other costs that enter into the retail price in addition to the price paid by the manufacturer for raw materials.

These other costs vary in different sections of the country but on the average are estimated to be per ton about as follows:

Bags	$1.20	Selling expenses	$1.50
Labor	1.00	Tag tax	.25
Overhead	2.25	Freight	2.50
Taxes	.75	Trucking	.75
Profit	1.00	Dealers' compensation	1.50
		Total distribution costs	6.50
Total manufacturing costs exclusive of raw materials	6.20	Total basic cost	12.70

Overhead includes a variety of costs, such as interest, losses by fire and shrinkage, chemical control, operation of plant, office expenses, etc. The above items are all independent of the plant-food content and would be charged for a mixture handled in the usual way even if it consisted entirely of filler, because such items must be paid for at the same rate on inert material as on the actual plant nutrients. Thus, the freight charge per ton on a 2–8–2 fertilizer is the same as on a 4–16–4 fertilizer, but only half as much of the latter has to be transported to supply the same quantity of plant food.

Fertilizer manufacturers publish schedules giving retail prices for many different grades of mixed fertilizers. From these price lists one may calculate the basic cost and the cost per unit of nitrogen, phosphoric acid, and potash in the following manner: Find the difference in price between two grades that differ only in their content of nitrogen and divide this by the difference in percentage of nitrogen. For example, if the price per ton of a 2–8–5 mixture on a delivered credit basis is $26.20 and that of a 4–8–5 mixture is $30.20, the charge for one unit of nitrogen is $\frac{30.20-26.20}{2}=\$2$. In like manner compute the price per unit of P_2O_5 and K_2O always, of course, using prices quoted on the same basis. Having found the unit charges for N, P_2O_5, and K_2O, multiply them by the corresponding percentages contained in any mixed fertilizer and subtract the sum from the quoted price to find the basic cost of that fertilizer. For instance, suppose the charges for N, P_2O_5, and K_2O are $2, $0.70, and $0.90, respec-

tively, and the cost of 1 ton of 4–8–4 is $28.88. Then the basic cost is:

Total cost		$28.88
4 units N at $2	8.00	
8 units P_2O_5 at $0.70	5.60	
4 units K_2O at $0.90	3.60	
Total cost of plant food		17.20
Basic cost		11.68

Once these factors are obtained they may be used to calculate the price of any grade not containing over 25 or 30 total units of plant nutrients and will be found to work fairly accurately for the State and season to which they apply for the goods of nearly all companies. Factors for Maine, however, will not apply in North Carolina, because economic conditions are quite different in these States. Average factors for several States in the 1938 spring season are given in table 7.

Table 7.—*Factors for computing the approximate price per ton on a delivered credit basis of standard mixed fertilizers containing not more than 25 percent of plant food in representative States*

Cost item	Maine	Delaware and Eastern Shore	North Carolina	Georgia	Indiana
Basic cost in 200-pound bags	$17.50	$12.65	$14.25	$11.95	$11.10
Cost per unit of N	2.10	2.25	2.50	2.50	2.00
Cost per unit of available P_2O_5	.60	.70	.55	.65	.90
Cost per unit of K_2O	.65	.65	.70	.70	.90

From the above analysis of retail fertilizer prices it is easy to see that it is in the interest of the farmer to buy high-analysis grades and that any change in fertilizer usage that increases the average grade consumed is in the interest of agriculture in general.

In 1934 a survey was made of the tonnage of each grade of mixed goods sold in the United States (*251*). The most popular grade was 3–8–3, with 14 percent of the total tonnage. To make this grade with the best and most economical materials now available it is necessary to add at least 500 pounds of inert filler to the ton of mixture. If these same materials were mixed without the filler the grade would be approximately a 4–11–4. At average retail prices, 4 tons of 3–8–3 cost $113 and 3 tons of 4–11–4 cost $98.80, or $14.20 less. Thus, by merely changing his order for fertilizer from 3–8–3 to the equivalent quantity of a 4–11–4 fertilizer, a farmer may save 12.6 percent of his fertilizer bill. The cost of 1 ton of 6–16–6 fertilizer under the same conditions as those quoted above for the 3–8–3 grade is $42.25 as compared with $56.50 for 2 tons of the 3–8–3 fertilizer, a difference in favor of the 6–16–6 mixture of $14.25, or 25 percent of the cost of the 3–8–3 mixture. The average cost under identical conditions of 1 ton of plant food in the form of several different grades with the same ratio of nitrogen, phosphoric acid, and potash is given in table 8.

It may be concluded that, in general, grades containing less than a total of 16 percent nitrogen, phosphoric acid, and potash, such as 3–8–3, 2–9–3, 0–10–4, and 2–8–2 are no longer economical. Approxi-

mately the same ratios of plant food may be more economically bought in 4-10-4, 3-12-5, 0-12-5, and 4-16-4 grades, respectively.

Table 8.—*Comparative costs of a ton of plant food in low and in higher analysis fertilizers*

Ratio of N-P_2O_5-K_2O	Grade	Total units of plant food	Total cost on a retail delivered-time price basis	Savings in higher analysis grade over lowest grade in group
			Dollars	*Percent*
1-2-1	4-8-4	16	185.12	
	5-10-5	20	170.04	8.1
	6-12-6	24	158.99	14.1
	8-16-8	32	150.28	18.8
	10-20-10	40	144.31	22.0
1-4-1	2-8-2	12	198.23	
	3-12-3	18	165.38	16.6
	4-16-4	24	150.02	24.3
	5-20-5	30	142.01	28.4

While the cost per unit of plant food in fertilizer mixtures decreases, as a rule, with increase in their plant-food content, a limit exists beyond which it is inadvisable to increase the grade of a fertilizer because too much of the primary elements may exclude a sufficient supply of the secondary fertilizer elements. That the plant-food content of a mixed fertilizer may be increased to at least 30 percent and still retain an ample proportion of all essential plant-food elements is shown by the formulas in table 3 (p. 530).

For many years the wholesale prices of ammonia, nitrate, and organic nitrogen were approximately the same. It was the general opinion at this time that all nitrogen carriers were not equally efficient, and that the use of these three forms of nitrogen in the same mixture gave better results than any one alone. Recent field tests indicate, however, that the differences noted in the relative efficiencies of the various nitrogen carriers are due, in part at least, to differences in their influence on the acidity of the soil, and that these differences will largely disappear if steps are taken to maintain the same reaction of the soil for all fertilizers.

When it was discovered that organic ammoniates could be used as stock feed with excellent results and that most of the plant-food elements in them were still available for fertilizer in the manure, prices on such materials began to rise gradually until at present insoluble organic nitrogen costs about four times as much as the equivalent quantity of nitrogen in soluble chemical forms. The proportion of insoluble organic nitrogen in a mixed fertilizer, therefore, at present has an important bearing upon its retail price. For instance, a 5-7-5 fertilizer with all nitrogen in the inorganic form costs the farmer in Florida at present about $30 per ton. With 20, 50, and 100 percent of the nitrogen in the organic form, the price under otherwise identical conditions is about $34, $40, and $50 per ton. Thus the retail price increases about $4 for each percent of nitrogen in the organic form. As already mentioned, more than three-fourths of the nitrogen in mixed fertilizers was formerly derived from organic ammoniates, but at present less than one-fifth of the nitrogen is so derived. By substituting

chemical nitrogen for organic nitrogen about 10 percent of the total expenditure for fertilizer can be saved.

The usual method of applying a mixed fertilizer to corn and cotton in the Southeast is to place it in the bottom of a furrow, throw a bed over it, and then wait for a rain to settle the bed, after which the seed is planted in the top of the bed. Since there is danger of injury to germination when all the nitrogen needed by the plant is applied in this way, the practice was adopted of applying part of the nitrogen later as a side dressing. A large number of recent experiments show conclusively that fertilizer planted simultaneously with the seed in a narrow band at the side of the seed does not injure germination and is very efficient in promoting high yields. It has been suggested, therefore, that the use of a sufficient quantity of ammonia nitrogen in a physiologically neutral mixture at planting time might eliminate the necessity of side dressing the crop later in the season. If this practice should prove just as efficient as the older one, a farmer could save about 7 percent of his fertilizer bill by making the change. He would also save the trouble of the extra applications.

Some farmers mix their own fertilizers. In general, the labor required can be more advantageously employed in other ways. The difference between the cost of the ingredients necessary and that of the ready-mixed goods in the case of high-analysis mixtures without filler is small. If a farmer desires a 3–8–3 or similar low-grade mixture, however, he can buy the necessary high-grade materials to make a ton for $5 to $6 less than the price of the commercial mixture. In this case he only needs to buy 1,200 to 1,500 pounds of material, since filler may be omitted and a saving can thus be made on all the overhead on this part of the mixture.

To sum up the economics of mixed fertilizers in a few words, it may be said: (1) That the substitution of inorganic nitrogen for insoluble organic nitrogen, when such a change does not impair the efficiency of the fertilizer, will save the farmer as much money as could be expected from cutting the wholesale price of chemical nitrogen, phosphoric acid, or potash fertilizer materials in half; (2) that a similar saving can frequently be made by applying all fertilizer at planting time instead of in split applications; (3) that a still larger saving would accrue to the farmer if filler were eliminated from fertilizers; and (4) that the farmer who uses double-strength in place of single-strength fertilizers makes a greater saving in his fertilizer bill than if the wholesale cost of all the materials entering into the single-strength mixtures were cut in half (*321*, *322*).

It is recognized that the supply of double-strength goods is limited at present to the demand and that the price might temporarily advance with a sudden greatly increased demand for fertilizers of this kind. The elimination of filler, however, should result in an immediate decrease in retail costs. A marked reduction per unit of plant-food in the average retail cost of mixed fertilizers is thus possible apart from that which results from a decrease in the cost of fertilizer materials. While it may be very difficult to lower the price of fertilizers further by cutting the cost of production, it is a very simple matter for any farmer who is not already doing so to reduce his fertilizer bill by proper selection of the fertilizer grades now on the market.

FERTILIZER CONTROL LEGISLATION

During the first decade of the fertilizer industry no laws existed for the protection of the buyer and honest manufacturer from fraud. No means were available to the buyer for passing on the quality of a fertilizer at the time of purchase, and its value could therefore not be determined until the end of the growing season. This encouraged unscrupulous persons to make extravagant claims for material of little or no value. Conditions of this kind had a very serious effect on the early development of the fertilizer industry and led to the adoption of the present system of fertilizer control.

Although Maryland, Massachusetts, North Carolina, and Virginia had passed laws affecting the sale of commercial fertilizers previous to 1873, none of these laws were effective in controlling fraud because they contained no provisions for collection and analysis of samples by a State official. The first effective fertilizer control law was approved by the Massachusetts Legislature May 26, 1873, and went into effect October 1, 1873. Under this act it was the duty of the secretary of the State Board of Agriculture to prosecute violators. Since that time fertilizer laws governing the sale of fertilizers have been enacted in all the States except Nevada, where the tonnage of fertilizer sold is very small. The enforcement of the fertilizer laws in each State is invested in a control official who is authorized to collect and analyze samples of the fertilizers that are sold or offered for sale in that State. The fertilizer laws of the different States invariably contain fiscal features which provide for taxes in one form or another that are sufficient at least to make the enforcement of the law self-supporting, and in many cases to yield a net income which is applied toward the maintenance of the State agricultural college or turned over to the State treasury for general purposes.

The general nature and purposes of the laws of the different States are similar. Periodical registration of brands and accurate labeling are required by the laws in all States. The nitrogen content of nitrogenous materials is expressed as NH_3 in South Carolina and as N in all other States. The grade of a fertilizer is expressed in the order $P_2O_5-NH_3-K_2O$ in South Carolina, as $P_2O_5-N-K_2O$ in Georgia, and as $N-P_2O_5-K_2O$ in all other States. Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Montana, Ohio, Pennsylvania, West Virginia, Oklahoma, Delaware, and Wisconsin require a minimum of 16 percent of total plant food in all mixed fertilizers; Florida, New Hampshire, North Carolina, Virginia, and Tennessee require a minimum of 14 percent, and Georgia, Arizona, and Colorado, a minimum of 12 percent. No other States have minimum requirements.

The laws of most States specify that all fertilizer analyses shall be made by the official methods of the Association of Official Agricultural Chemists. In Alabama, North Carolina, South Carolina, and Virginia the manufacturer must declare whether the mixture is "acid-forming" or "nonacid-forming." Misissippi requires a statement on the tag of all sources of nitrogen, while Alabama, California, Florida, Georgia, Idaho, Montana, Nebraska, Oregon, South Dakota, Virginia, and West Virginia require a statement as to all plant-food sources. A recent amendment to the fertilizer law of South Carolina

provides that each fertilizer container must carry not only information on the materials used in the formulation of the mixture but also their percentage by weight and plant-food content.

The laws of the various States also differ in the statement required on the tag with respect to the form of the nitrogen used in the mixture. Thus Alabama and South Carolina require a statement as to the content of water-soluble and water-insoluble nitrogen; Georgia and Virginia of organic and inorganic nitrogen; while Florida requires a statement as to the minimum content of ammonia, nitrate, soluble-organic, and insoluble-organic nitrogen in the mixture. In many States it is required that fertilizer mixtures containing components with comparatively inert nitrogen, such as hair, leather, and wool waste, carry a statement to this effect on the label.

In expressing the guaranteed analysis of a fertilizer, a leeway of 0.1 to 0.2 percent for nitrogen, and 0.2 to 0.3 percent for phosphoric acid and potash is allowed in some States. In a number of other States the tolerance is based on a percentage of the total value of the fertilizer, usually 3 to 5 percent. In the remaining States no tolerance is allowed. Penalties of varying degrees of severity are prescribed for failure to comply with the analysis guarantee and for other violations of the fertilizer laws. Periodical publications are in many cases required of the State official in charge of the administration of the fertilizer law. These publications contain lists of registered brands, guaranteed and found analyses, percentages of different forms of nitrogen in the samples analyzed, and other information useful to the consumer and the industry.

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IT IS NOT ENOUGH *to have the right amounts of the right fertilizers; they must also be placed rightly if they are to have maximum effectiveness and not be wasted. This article discusses broadcasting versus placing in the row close to the plants. What are the effects of the two methods on rapidity of growth and time of maturity? On injury by drought? On the availability of nutrients? What is the best placement for bands—beside the seed, or over it, or under it? Is it better to apply fertilizer all at once, or at different times? This article discusses these questions, and an appendix gives recommended methods for important crops.*

Methods of Applying Fertilizers

By Robert M. Salter [1]

APPLYING fertilizer in the right place is fully as important as applying the right analysis or the right amount. This highly important fact was largely overlooked by soils investigators until the last 15 years. Even today it is not fully appreciated by farmers. Many continue using antiquated machines and methods whose low efficiency has been clearly demonstrated.

Knowledge of the principles and practice of fertilizer application has expanded rapidly in recent years. Scientific studies in the laboratory and greenhouse, carefully controlled hand- and machine-placement studies in the field, and performance tests with commercial fertilizer distributors have all contributed to this advance. Progressive manufacturers of farm equipment have made rapid progress in adapting this information to the improvement of fertilizer distributors. In considerable degree, the progress in this field of applied research has resulted from the program of investigations conducted cooperatively by the Bureaus of Agricultural Engineering, Chemistry and Soils, and Plant Industry, of the United States Department of Agriculture, and the State experiment stations of more than 20 fertilizer-using States. This program has been actively sponsored by the National Joint Committee on Fertilizer Application, an organization set up in 1925 and composed of official representatives of the American Society of Agricultural Engineers, the American Society of Agronomy, the American Society for Horticultural Science, the Farm Equipment Institute, and the National Fertilizer Association.

Fertilizer is ordinarily applied in either of two ways: (1) Over the entire soil surface by the method commonly referred to as broadcasting, or (2) in a localized area close to the seed or plant, usually

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termed "hill or row placement." Broadcast applications commonly include a separate operation in addition to seeding. The fertilizer may be spread on the surface, with or without incorporation in the soil, or it may be placed below the soil surface in closely spaced rows by the use of a fertilizer drill. Hill or row applications are usually made through a fertilizer attachment on the planter; hence they do not involve a separate operation and are more economical of labor unless the separate operation of applying the fertilizer by the broadcast method may be made to substitute for a tillage operation. Practice varies, however, and in some cases with hill or row placement the seed and fertilizer are incorporated with the soil in separate operations, using either machine or hand methods.

The maximum yield of any crop is apt to be realized when the supply of nutrients is not below the optimum at any period. Stunting of the plant from deficiencies of nutrients at any time generally results in a reduction in yield, although this does not always happen with crops that do not use the full growing season. With many plants, a lack of nutrients not only reduces the amount of growth but slows up the progress of the growth cycle, causing late fruiting and delayed maturity. In Ohio, the same variety of corn, planted on the same day on unfertilized and on well-fertilized soil, has varied as much as 28 days in the time from planting to silking.

The ability of a soil to yield up available nutrients to crops is influenced considerably by the amount of biological activity taking place. Hence, deficiencies of nutrients frequently occur early in the growing season, especially in years with below-normal spring temperatures or with excessive or deficient soil moisture. Moreover, soils of low natural fertility are more apt to compare unfavorably to naturally fertile soils early in the season than later, when temperature and moisture conditions become more favorable.

PRINCIPAL EFFECTS OF LOCALIZED PLACEMENT OF FERTILIZER

Since fertilizers are known to move only slight distances horizontally, any fertilizer located outside the spread of the root system is without effect. By hill or row placement, the supply of nutrients at the disposal of the young plant is increased as compared to broadcast applications. For example, with corn check-planted 42 inches each way, the fertilizer at the disposal of each hill with broadcast application is spread over an area of 1,764 square inches. With hill application the area encompassing the fertilizer will usually be less than 30 square inches. The ratio of concentration with respect to the young plant for the two methods is roughly 60 to 1.

By insuring an abundance of nutrients soon after germination, localized placement favors rapid early growth (fig. 1). With many crops this also means earlier ripening. The principle, as applied to corn, is illustrated in table 1, in which are shown the results from placing increasing fractions of a 500-pound application of 4–12–4 fertilizer in the hill, the remainder in each case being applied broadcast.

The rapid early growth and earlier maturity resulting from localized fertilizer placement is generally, although not always, an economic advantage. Farmers have observed that crops thus fertilized often

can be more quickly and effectively cultivated. With full-season crops, hastened maturity minimizes danger of frost damage and may permit the growing of later, higher yielding varieties. In areas characterized by midsummer drought, the yield of crops that ripen before the dry period may be increased. Thus wheat fertilized in the drill row exceeded the yield of wheat fertilized broadcast by 2.0 bushels in Ohio (*227*)[2] and by 7.8 bushels in Kansas (*94*). With many market-garden crops, earliness permits marketing at higher prices, and localized placement may have an economic advantage out of all proportion to the benefit in yield. Data from a comparison

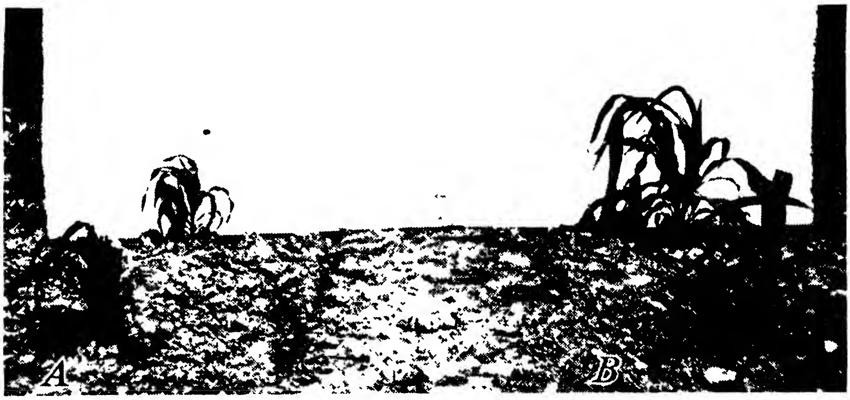

FIGURE 1.—Hill application hastens early growth of corn: *A*, Corn fertilized with 300 pounds of 3-12-4 per acre broadcast; *B*, 200 pounds 3-12-4 broadcast plus 100 pounds in the hill. (Courtesy Ohio Agricultural Experiment Station.)

Table 1.—*Effects on corn yield of varying proportions of fertilizer applied in the hill and broadcast* [1]

Plot No.	Proportion of fertilizer (500 pounds 4-12-4) applied in hill [2]	Height of corn at 8 weeks	Planting to silking	Moisture at husking	Yield [3]	Increase over unfertilized [3]
	Percent	*Inches*	*Days*	*Percent*	*Bushels*	*Bushels*
1	0	19.8	89	41.3	31.5	6.7
2	25	29.8	86	38.5	40.8	16.7
3	50	31.4	86	38.6	42.1	19.2
4	75	34.1	85	38.4	45.7	22.9
5	100	32.7	84	39.4	42.3	18.9
Check [4]		14.8	92	45.1	24.6	

[1] Ohio Agricultural Experiment Station, Canfield silt loam, 4-year average.
[2] Fertilizer applied in hill mixed with soil to depth of 1½ inches over area 3 by 10 inches. Remainder broadcast.
[3] On basis of 15 percent moisture.
[4] Unfertilized.

of broadcast and row application for bush lima beans at the Virginia Truck Experiment Station in 1935,[3] showing the effects on early and later harvests, are presented in table 2.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.
[3] ZIMMERLEY, H. H., PARKER, M. M., and CUMINGS, G. A. DISCUSSION OF MACHINE FERTILIZER PLACEMENT EXPERIMENTS IN VIRGINIA. Natl. Joint Com. Fert. Appl. Proc. 11: 73-80. 1935. [Mimeographed.]

Table 2.—*Effect of row application in increasing early harvest of bush lima beans*

Method of application (1,000 pounds fertilizer)	Yield per acre of unshelled beans		
	Early harvest	Later harvest	Total harvest
	Pounds	*Pounds*	*Pounds*
Broadcast at planting	2,910	1,230	4,140
In row [1]	3,850	1,020	4,870
Gain for row placement	940	−210	730
Unfertilized yield	2,310	670	2,980

[1] In band 2 inches to side and 1 inch below seed level.

With cotton, early maturity aids in reducing boll weevil damage. With winter cereals, resistance to winter injury results from the greater fall root growth that attends the application of fertilizer in the drill row. Another advantage of close placement of fertilizer, noted by Magistad and Truog (*235*), is that—

application of fertilizer in the hill increases the osmotic pressure of the sap of young corn plants, which in turn lowers the freezing point of the plant from one to two degrees centigrade. This is often sufficient to prevent plants from being frozen by late spring frosts when they are not too severe.

The advantages of localized over broadcast application are less marked on soils of high natural fertility and when the acre application of fertilizer is high, both conditions tending to increase the supply of nutrients to the young plant.

Increased early growth and hastened maturity resulting from localized placement is not always advantageous. Actual damage may result, expecially with fall-maturing crops in regions of mid-summer drought. The effect may be either to advance the maturity of the crops into the drought period or to magnify the immediate damaging effects of the dry weather, causing the crop to fire. It was formerly believed that this type of injury resulted from restricted root development, the assumption being that localized fertilizer placement tended toward a localized root development, but experiments have failed to support this idea (*145*, *259*, *367*, *419*). It is probable that such injury is the direct result of the enhanced early growth, which results in a more complete withdrawal of soil moisture preceding the drought and in a larger need for water.

Localized placement results in more complete utilization of nutrients by the immediate crop and smaller residual effects than broadcast application. In a 6-year test at the Ohio Station, 300 pounds of 3–12–4 applied broadcast for corn gave increases of 9.0 bushels of corn and 6.6 bushels for the following oat crop. A smaller application, 200 pounds, of the same analysis in the hill increased the corn yield 11.4 bushels, but the oat crop not at all. In some instances irregular growth has been observed in crops following hill or row fertilized crops. Although claimed by some to be a disadvantage of localized placement, it is more properly an indication that the subsequent crop is not adequately fertilized.

Soluble phosphate and potash fertilizers tend to become fixed and less available through contact with soil. This effect increases with the extent and duration of the contact. By concentrating the fertilizer within bands or mixed with only a small volume of soil, the opportunity for fixation is reduced. It is believed that this fact is in part responsible for the increased efficiency shown by hill or row applications on many soils, especially on heavy soils rich in colloidal material.

PLACEMENT OF THE FERTILIZER IN THE SOIL

The superiority of localized applications of fertilizer for crops planted in hills or rows for most conditions is now well recognized. In attempting to use the method with the fertilizer-distributing machinery at their disposal farmers have obtained variable and not infrequently disappointing results. Difficulties have arisen from impaired germination and damage to young seedlings. The problem lies in getting the fertilizer close enough to give efficient utilization without getting it so close that the concentration of fertilizer salts in the soil solution about the seed and young plant becomes damagingly high. Many studies have been made comparing different fertilizer "patterns" with the more important crops under a wide variety of soil and climatic conditions. From these studies certain generalizations can be drawn and reliable recommendations made for many crops. Additional work is needed for some crops and conditions.

Knowledge of how fertilizer salts move in the soil aids in understanding the results obtained with different placements. Excepting organic carriers such as tankage or cottonseed meal, most of the nutrients in mixed fertilizers are carried in the form of water-soluble materials. These tend to go into solution in the soil water and move about, the extent of movement depending upon the amount of rain and the nature of the materials present in the fertilizer. Movement is chiefly the result of the fertilizer salts being carried along with the soil water. Most of this movement is up and down—down following a rain and up at times when moisture is evaporating from the surface. Numerous studies have shown that almost no lateral movement of fertilizer salts occurs.

Among fertilizer materials, nitrates move most freely, potash and ammonium salts somewhat less, and phosphates, even though water-soluble, very little. The movement is controlled in part by the degree to which the different compounds are fixed by the soil. Data obtained by Sayre and Clark (*337*) in a greenhouse experiment at the New York State Station support the idea that it is chiefly the soluble nitrogen and potash salts that move about and cause damage to germinating seeds or seedlings from improperly placed fertilizers.

Excessive salt concentration in the soil solution coming into contact with the seed or young plant seems to be the most important cause of fertilizer injury, the principal effect being to retard the entrance of water into the seed or rootlets or to withdraw water from the young shoots (*56*, *70*, *367*, *419*). The nature of the fertilizer materials is not without importance, since they may be such as to produce excessive local acidity or alkalinity, or exert a direct toxic action on the young plant, as in the case of cyanamide, fertilizers containing borax, or fertilizers that produce free ammonia in toxic concentrations through

hydrolysis (urea) or bacterial decomposition (cottonseed meal). Injury from phosphates, sulphates, chlorides, and nitrates increases in the order named. Damage is apt to be more severe in sandy soils than in clay or muck soils. It is worse in dry or hot weather than in wet or cool weather. Crops differ in their sensitivity to injury. In general, the legumes—beans, soybeans, peas, clover, alfalfa, etc.—are most easily injured, although cotton and crops of the cucurbit family are also highly sensitive. With most crops injury to the

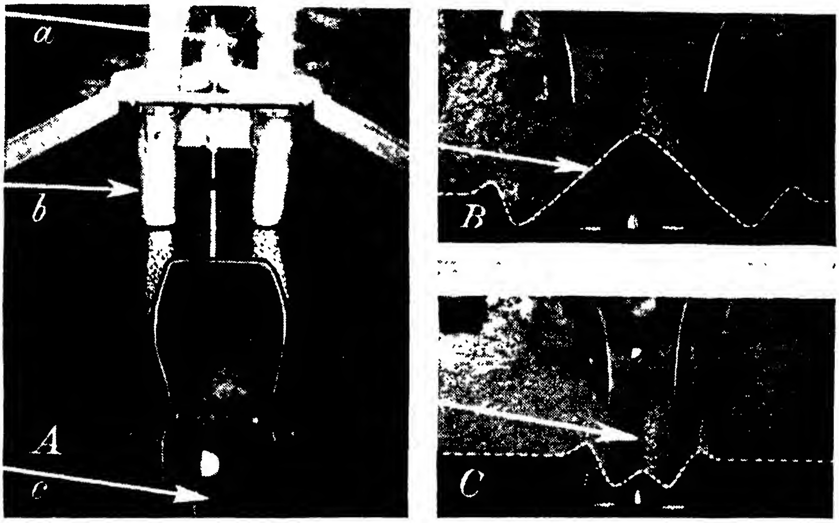

FIGURE 2.—Placement of seed piece and fertilizer by modern potato planter: *A*, *a*, Double disk openers make furrows for placement of fertilizer in bands; *b*, fertilizer drops through spouts in bands 2 inches wide and 2 inches from seed, either on level with it or below; *c*, groove prevents seed piece from rolling out of place. *B*, Ridge-covering method—note relative position of seed and fertilizer. *C*, Deep planting, shallow covering in furrow method.

young sprouts occurs at lower fertilizer concentrations than does actual impairment of germination. However, both are frequently involved. Root damage to transplants is also a frequent source of trouble.

Side Bands Best All-Around Pattern

No single fertilizer pattern has been found superior with all crops and under all conditions. Almost without exception, however, in the numerous comparisons that have been made, placing the fertilizer at the sides of the seed or plant has been most efficient (fig. 2). On the average, no other placement appears to be even a close second. Most damaging is placement directly in contact with the seed, although this placement is sometimes advantageous where the rate of application is low and plenty of rain falls soon after planting. Placement in bands directly over the seed is usually inferior, the fertilizer tending to wash down on the seed and injure it. Bands directly below the seed are little better if placed at shallow depths, the fertilizer tending to rise with the capillary water and cause trouble. Deeper bands below the

seed have given good results with some crops but entail mechanical difficulties, especially on heavy soils. Mixing the fertilizer in the row with the seed or under the seed is sometimes good, but often not if the soil happens to remain fairly dry after planting. It is relatively poorer as the rate of application increases.

The general superiority of side-band placement is easily explained by the tendency of fertilizer salts to move up and down but only slightly in a horizontal direction. The seed lies in soil free of fertilizer, and both young roots and shoots can develop without coming into contact with an excess of fertilizer salts. A narrow band of fertilizer-free soil at the side of the seed, between it and the fertilizer band, serves to prevent damage.

The effectiveness of lateral-band placement in protecting the seed against injury from excess salt concentration is illustrated by the data in table 3 (*82*) showing the results of a South Carolina experiment in which 800 pounds per acre of a 4–8–4 fertilizer was applied to cotton in different placements.

Table 3.—*Effects on salt concentration in seed zone, germination, and yield of cotton with different fertilizer placements in Norfolk very fine sandy loam*

Fertilizer placement (800 pounds per acre 4-8-4 on Apr. 16)	Soluble salts in seed zone Apr. 30 [1]	Seedlings above ground May 6	Yield per acre
	Parts per million	*Number*	*Pounds*
No fertilizer	71	186	760
Direct contact with seed	11,819		95
Mixed with soil below seed	1,202	129	835
1¾ inch band:			
1 inch below seed	1,335	19	122
2 inches below seed	1,173	121	371
3 inches below seed	621	173	735
4 inches below seed	337	215	1,062
Bands 1½ inches to each side:			
1 inch below seed level	283	203	1,057
2 inches below seed level	123	211	1,147
3 inches below seed level	99	210	1,143

[1] Concentration of soluble salts in parts per million of the soil within one-half inch of the seed.

The fertilizer bands may vary from ¾ to 2 or more inches in width and be placed to give a horizontal separation of seed and fertilizer of ¾ to 2½ inches. No definite rules can be laid down as to the best width or spacing of the fertilizer bands. However, examination of the results of a large number of tests with different crops and soils indicates that the heavier the rate of application, the coarser textured the soil, and the more sensitive the crop, the wider should be the fertilizer bands or the greater should be the separation of seed and fertilizer. Increasing the width of band acts like increasing the horizontal distance between seed and fertilizer in reducing injury. Narrow bands—about three-fourths inch wide—spaced to give a separation of seed and fertilizer of from ½ to 1 inch have been found satisfactory on the commercial corn planters used in the North Central States where the acre rate is relatively light—100 to 200 pounds—and the soil predominantly fine in texture. In contrast, modern distributors for applying fertilizers to potatoes place it in bands about 2 inches

wide and 2 inches at the side of the seed. In this case the rate of application may be as high as a ton per acre, and the crop is often planted on sandy soils.

With side-band placement the desired depth of band varies with the nature of the crop. In general, best results have been obtained when the fertilizer is placed at or somewhat below the level of the seed. With corn, seed level to 1 inch below appears best; with potatoes, seed level; and with cotton, about 2 inches below seed level. Applications much above seed level are apt to be disturbed in cultivation and tend to give poor results if dry weather follows planting.[4]

Single bands have been compared with bands at both sides of the seed with corn, cotton, potatoes, sugar beets, snap beans, and field beans. The differences in yield obtained have been small as a rule and not consistently in favor of either method. However, the two-band method has been superior in more than half of the trials and is probably preferable where the acre rate of application is high.

With hilled crops or those space-planted in rows, a few comparisons have been made of continuous bands and broken bands. Obviously, with the latter, the concentration of fertilizer near the seed is increased in proportion as the total length of band is reduced. In a 5-year test with corn planted in hills spaced 42 inches apart each way at the Indiana Station,[5] 125 pounds of 0-12-8 fertilizer placed in two bands 7 inches long, 1 inch wide, and 2 inches apart produced an average increase of 12.2 bushels, compared to only 7.6 bushels for drilling the fertilizer in two continuous bands 1 inch wide and 2 inches apart. However, in 1936 in tests comparing continuous and broken bands for potatoes in New York (Long Island), New Jersey, Virginia, and Ohio,[6] the continuous-band method led in 17 out of 23 comparisons. In the Ohio test, the only one in which rates less than 1,500 pounds per acre were included, the broken-band method led at the lightest rate (500 pounds of 4-8-8) but was inferior to the continuous-band method at the other rates in increasing degree as the rate of application increased. In general, it appears that broken bands may be preferable at relatively low rates of application and continuous bands at relatively high rates.

Split Applications

These include methods in which a part of the fertilizer is applied in the hill or row at planting and a part broadcast, usually just before planting; application of a part in direct contact or very close to the

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[4] SALTER, ROBERT M. FURTHER FERTILIZER HAND PLACEMENT EXPERIMENTS WITH CORN. Natl. Joint Com. Fert. Appl. Proc. 8: 78-80. 1932. [Mimeographed.]

[5] WIANCKO, A. T., and MILES, S. R. HILL VERSUS ROW APPLICATION OF FERTILIZER FOR CORN, 1936 AND FIVE-YEAR AVERAGE, 1932-1936, AT LAFAYETTE, INDIANA. SOIL TYPES: CROSBY AND BROOKSTON SILT LOAMS Natl. Joint Com. Fert. Appl. Proc. 12:51. 1936. [Mimeographed.]

[6] BROWN, B. E. FERTILIZER PLACEMENT STUDIES WITH POTATOES IN 1936. Natl. Joint Com. Fert. Appl. Proc. 12: 60-61. 1936. [Mimeographed.]

CHUCKA, JOSEPH A. FERTILIZER PLACEMENT STUDIES OF POTATOES—MAINE—1936. Natl. Joint Com. Fert. Appl. Proc. 12: 62-64. 1936. [Mimeographed].

HOUGHLAND, G. V. C., SMITH, ORA, and CUMINGS, G. A. FERTILIZER PLACEMENT STUDIES WITH POTATOES ON LONG ISLAND. Natl. Joint Com. Fert. Appl. Proc. 12: 65-67. 1936. [Mimeographed.]

——— STRONG, W. O., REDIT, W. H., and SCHWENLEBER, L. G., Jr. FERTILIZER PLACEMENT STUDIES WITH POTATOES IN VIRGINIA. Natl. Joint Com. Fert. Appl. Proc. 12: 69-72. 1936. [Mimeographed.]

MARTIN, WM. H. FERTILIZER PLACEMENT STUDIES WITH POTATOES IN NEW JERSEY. SEASON OF 1936. Natl. Joint Com. Fert. Appl. Proc. 12: 68. 1936. [Mimeographed.]

BUSHNELL, JOHN. FERTILIZER PLACEMENT STUDIES WITH POTATOES IN OHIO. SEASON OF 1936. Natl. Joint Com. Fert. Appl. Proc. 12: 73-74. 1936. [Mimeographed.]

GRANTHAM, GEO. M. REPORT OF FERTILIZER PLACEMENT FOR POTATOES IN 1936. Natl. Joint Com. Fert. Appl. Proc. 12: 75. 1936. [Mimeographed.]

seed and a part in side bands or other positions less likely to cause injury, both applications at planting; application of a part in the hill or row at planting and a part in the form of delayed side dressings, usually drilled in bands at the side of the row.

Theoretically it would seem that a split application in which only that amount of fertilizer required to support the plant properly during early growth is placed in the hill or row, and the remainder more generally distributed through the root bed, where it would be accessible to a larger part of the total root system, might be superior to placing the full amount in the hill or row. ' Actually, the available data do not support this assumption; as a rule the broadcast portion either fails to pay for itself or gives less return than does a corresponding increase in the hill or row treatment. It is possible that the increased opportunity for fixation of phosphoric acid and potash by the soil and for leaching of nitrogen may contribute to the ineffectiveness of the broadcast application. It would appear that these effects might be lessened by applying the more widely distributed portion in bands or spots or by delaying the application until the roots had been extended into the zone of application. The evidence on this question is too meager to permit definite conclusions. Ten experiments with cotton in six States in 1934 [7] included comparisons of (1) one-sixteenth of fertilizer in contact with seed, balance in bands at each side, (2) one-fourth of fertilizer above the seed, balance in bands at each side, and (3) the full application in bands at each side of the seed. The average yields for all tests showed no advantage for the split applications over placing all of the fertilizer at the sides of the seed.

A common practice with some vegetable crops receiving heavy fertilizer treatment, especially on the sandy soils of the Coastal Plain, is to drill a part of the fertilizer in the row at planting and the remainder along the side of the row after the crop is well started. Moreover, with cotton, corn, tobacco, sugar beets, and a number of vegetable crops, delayed side dressings with nitrogen fertilizers are often used as supplements to complete fertilizers applied in the row either at or before planting.

Few experiments have been reported comparing the placing of the full amount of fertilizer in bands at the side of the seed or plant at planting time with application of a part of the fertilizer in this position and the remainder as a delayed side dressing to the growing crop. At the New York State Station, in tests covering 3 years with cabbage and beans and 2 years with tomatoes,[8] applying one half of a 600-pound application of 4–16–4 in bands at the side of the seed or plant at planting and the remainder as a delayed side dressing has shown poorer results than applying the full amount by the former method with cabbage and not significantly better results with beans and tomatoes. In Virginia experiments,[9] splitting a 1,000-pound

[7] CUMINGS, G. A. GENERAL SUMMARY OF COOPERATIVE FERTILIZER PLACEMENT EXPERIMENTS WITH COTTON IN SEVEN STATES, 1934. Natl. Joint Com. Fert. Appl. Proc. 10: 64-71. 1934. [Mimeographed.]

[8] SAYRE, CHARLES B. FERTILIZER PLACEMENT FOR VEGETABLE CROPS. Natl. Joint Com. Fert. Appl. Proc. 10: 52-54. 1934. [Mimeographed.]

——— EFFECT OF FERTILIZER PLACEMENT ON YIELD . . . CANNERY PEAS, CABBAGE, TOMATOES, WAX BEANS. Natl. Joint Fert. Com. Appl. Proc. 11: 81-82. 1935. [Mimeographed.]

——— in cooperation with CUMINGS, G. H. FERTILIZER PLACEMENT EXPERIMENTS WITH VEGETABLES AT GENEVA, NEW YORK—DISCUSSION OF 1936 RESULTS. Natl. Joint Com. Fert. Appl. Proc. 12: 39-44. 1936. [Mimeographed.]

[9] ZIMMERLEY, et al.; see footnote 3, p. 548.

application for tomatoes has been slightly better than applying the full amount at planting in each of 2 years. The same was true with a 2,000-pound application to spring cabbage in a 1-year test, but not with onions, also a 1-year test. In general it appears that if the fertilizer is properly placed in the hill or row at planting time, the advantage of splitting the treatment, applying a portion as a delayed side dressing, is not apt to be large. Particularly is this likely to be true with fertilizers relatively high in phosphoric acid and potash compared to nitrogen.

Where large applications of nitrogen are the rule, the situation may differ owing to the tendency of this nutrient to be lost by leaching and on some soils to be fixed biologically. Delayed side and top dressings with nitrogen fertilizers have been found advantageous in some cases. At the South Carolina Station (*316*) applying half of a 200-pound application of nitrate of soda to cotton at planting and half at chopping was found superior to applying the full amount at planting time; with corn also, applying the full amount of nitrate when the crop was knee high was superior to applying either the full amount, or fractional amounts, at either earlier or later periods. On the other hand, Schreiner and Skinner (*351*) found with cotton on an important cotton soil of the Coastal Plain that the application at time of planting of all of the nitrogen, whether the source was nitrate of soda, sulphate of ammonia, or urea, gave in nearly every instance results as good as or better than delayed or split applications. Similar results have been reported by the Alabama (*469*) and Georgia (*39*) Stations. Likewise in uniform cooperative tests in North Carolina, South Carolina, and Georgia in 1936, with both acid and neutral fertilizer mixtures, delayed application of one-half of the nitrogen on the average gave no advantage over applying the full amount in side bands at planting.[10] With winter wheat at the Ohio Station (*288, pp. 62, 66, 73, 77*) only small amounts of nitrogen have been found profitable in the fertilizer applied at planting, whereas in normal seasons good returns are obtained from supplementary additions of mineral nitrogen fertilizers applied as top dressings in March or April. Similarly, at the same station, 16 pounds of nitrogen as sulphate of ammonia per acre, applied as part of a complete fertilizer in the hill for corn, produced a 5-year increase of only 1.7 bushels, whereas 20.5 pounds of nitrogen in the form of a delayed side dressing of sulphate of ammonia increased the yield 8.5 bushels as a 3-year average on the same soil.

The conditions under which divided or delayed application of nitrogen fertilizers are advantageous are not clearly indicated by the data at hand, although under conditions favorable to loss by leaching, as in the case of fall-planted crops, their desirability can probably be taken for granted.

FERTILIZER-DISTRIBUTING MACHINERY

Commercial fertilizer-distributing machinery varies widely in type depending upon the method of placement desired, the rate of application, the nature of the crop, and the time of application, whether

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[10] CUMINGS, G. A., REDIT, W. H., HUMPHRIES, W. R., and SKINNER, J. J. GENERAL SUMMARY OF FERTILIZER PLACEMENT STUDIES WITH COTTON, 1936. Natl. Joint Com. Fert. Appl. Proc. 12: 76–82. 1936. [Mimeographed.]

before, at, or after planting. Twenty-three different classes of machines were recognized in a recent survey of commercial fertilizer-distributing machinery made by the National Joint Committee on Fertilizer Application and published in a report [11] presenting comparative data on mechanical design and fertilizer placement. However, with regard to placement, all machines place the fertilizer (1) broadcast, (2) in spots or broken bands, or (3) in continuous rows. Again, they may be divided into (1) machines used only for applying fertilizer, (2) combination machines for applying fertilizer and planting the crop in one operation, (3) combination machines for applying fertilizer and tilling the soil in one operation, and (4) machines for applying fertilizer in solution with irrigation water. A detailed consideration of even the major types of distributors would exceed the scope of the present article. However, certain general features determining the practical efficiency of fertilizer distributors will be pointed out (see also (*186*)).

Placement of fertilizers.—This should be given first consideration in choosing a distributor. Placement should be in accord with sound agronomic principles, previously discussed. Although rapid improvement is being made in commercial distributors, many machines are still on the market that are far from satisfactory in this respect. Moreover, much of the equipment on farms is obsolete in design and could be profitably replaced with modern and more efficient types.[12]

The variability in efficiency of commercial distributors intended for use with a single crop is illustrated by the results obtained in a field comparison of 20 different machines used for applying fertilizers to cotton in South Carolina (*81*, *247*). The test was conducted on two soils, a Norfolk coarse sand and a Cecil sandy clay loam. Both tests included eight machines used for applying the fertilizer in an operation separate from planting. The test on the Norfolk soil also included 10 machines applying the fertilizer and planting the seed in one operation, and 6 machines of this type were included in the test on the Cecil soil. In both cases plots were included on which the fertilizer was uniformly distributed by hand. The same kind of fertilizer, a 12 24-12, was employed throughout and an effort was made to apply as nearly as possible the same rate per acre, 267 pounds. On the Norfolk soil the stand of plants 32 days after planting ranged with the different machines from 12 to 91 percent of that produced on the unfertilized plots, whereas the yield of cotton ranged from 28 to 86 percent of the yield obtained from uniform hand placement of the fertilizer. Similarly, on the Cecil soil the stand 22 days after planting ranged from 17 to 101 percent of the stand on the unfertilized plots, and the yield from 38 to 99 percent of that from uniform hand distribution of the fertilizer.

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[11] CUMINGS, G. A., BATEMAN, FRED H., CALLISTER, G. J., SKINNER, J. J., and ZIMMERLEY, H. H. A SURVEY OF FERTILIZER DISTRIBUTING MACHINES ON THE MARKET MADE BY THE NATIONAL JOINT COMMITTEE ON FERTILIZER APPLICATION . . . 6 pp. November 1936. [Mimeographed and distributed by the National Fertilizer Association.]

[12] According to the Bureau of Agricultural Engineering of the U. S. Department of Agriculture there are in use on American farms 5,000,000 machines that apply fertilizer either at the time of planting or as a separate operation before or after planting. Many of these are 10 to 20 years old and more or less obsolete insofar as fertilizer application is concerned. Many machines, otherwise good, could be modernized by new parts or attachments. The replacement of the others with modern machines, properly designed to place the fertilizer in accordance with the principles herein stated, should bring substantial return on the investment required.

Uniformity of delivery.—An important defect noted with several of the machines used in the foregoing test with cotton was irregular distribution in the row, there being a tendency for the rate to vary from high to low at definite and repeated intervals. This irregularity was reflected in irregular germination, growth, and final yield of the crop. It was concluded that for row distributors, uniformity of distribution was highly important. Uniformity of distribution is equally desirable with broadcast or spot placement and should be attainable with both light and heavy applications.

Ease of adjustment.—The rate of delivery should be capable of rather close adjustment and the device controlling the rate should be so designed that the same setting will give very nearly the same delivery on successive occasions, eliminating the need of recalibrating each time the machine is used. On many machines the change in rate between successive adjustment points is entirely too large. On some, changing the rate is tedious and time-consuming.

Adaptation to different types of fertilizers.—Many machines originally designed to handle the common powder form of fertilizer will not distribute properly the new free-flowing granular fertilizers. Since the latter offer certain advantages—less tendency to cake in storage, less segregation in drilling, flow less affected by weather, etc.—they may be expected to increase in popularity, and in purchasing a new distributor it may be advantageous to choose one that will handle them satisfactorily.

Range in rates.—A distributor should be capable of applying both the lightest and heaviest rate likely to be required for the crops for which it is intended. In some cases farmers have been unable to take advantage of the economies in cost and labor of application attending the use of concentrated fertilizers because they could not adjust their distributors to apply the smaller acre rates required with such fertilizers. Farmers having this difficulty should consult the manufacturer of their distributor since, in many cases, only a simple and inexpensive change is required to overcome it.

Size of hopper.—The hopper should be large enough to obviate the need for frequent refilling and for stops in the middle of the field.

Visibility of feed.—In order to detect stoppages or empty hoppers quickly, visibility of feed is desirable. This is particularly true with machines in which the fertilizer is delivered through tubes.

Hopper agitators.—These should be so designed as to prevent bridging and should work equally well when the hopper is full or nearly empty.

Easy emptying and cleaning.—Much difficulty from broken parts and inefficient operation results from not emptying, cleaning, and oiling a fertilizer distributor after each period of use. Moreover, most fertilizers tend to corrode metals, and failure to clean the distributor may shorten its life materially. Ease of emptying and cleaning is advantageous in facilitating these operations.

Improved Distributors Now Available

Rapid improvement has been taking place in the design of commercial fertilizer-distributing equipment, particularly with respect to the placement of the fertilizer. Combination planters and fertilizer distributors

that place the fertilizer in bands at the side of the seed now on the market include two-row corn planters, potato planters, cotton and bean planters, and small hand planters used in planting vegetable crops. Transplanters adapted for setting tobacco, tomato, cabbage, and other crops, carrying fertilizer attachments for applying the fertilizer in bands at the side of the plant, are also available, as well as machines for side dressing row-planted crops that drill the fertilizer in a band along the side of the row. In some cases the distributor is combined with a cultivator.

Continued improvement of commercial distributors is to be expected. One factor limiting improvement has been the fact that farmers have not appreciated the need for change, and hence the demand for improved machines has not justified the investment necessary in manufacturing them and placing them on the market. In some cases improvement has been limited by the power available on the farm. For example, it is difficult to design a combination planter and side-band distributor for cotton that is both light enough and cheap enough to replace the equipment now in use on farms where cotton is planted in single rows with one-mule power. More experimental work is needed with some crops before new distributors are developed. This is true in the case of machines employed for planting certain vegetable crops in closely spaced rows. The same applies to distributors for use on established meadows and pastures.

Recommended methods for applying fertilizers to important crops are given in the Appendix in a form suitable for ready reference by growers.

APPENDIX

Recommended Methods of Fertilizer Application for Important Crops

Prevailing methods of applying fertilizers vary widely with different crops and for the same crop in different regions. In part, these variations reflect different methods of culture, different types of soil, and different amounts and kinds of fertilizers used. Comprehensive surveys of prevailing methods of planting and fertilizing field and vegetable crops have recently been made by the National Joint Committee on Fertilizer Application.[13]

Investigations dealing with methods of application have advanced to a stage where fairly definite recommendations can now be made for several of the major crops. For a considerable list of crops, however, the information yet available is too meager to permit such recommendations, although it may be inferred from the general superiority already shown by side-band placement that some modification of this method is apt to be an improvement over other methods now in use for hill and row planted crops. Recommended methods of application for certain important crops follow:

Corn

Hill or row application is generally superior to broadcasting. When corn is check planted, the fertilizer should be dropped in the hill and not drilled. Hill applications are best applied in two bands, 6 to 8 inches long on each side of the seed and separated from it by one-half to 1 inch of fertilizer-free soil and in a depth

[13] Cumings, G. A., Bateman, Fred H., Callister, G. J., Skinner, J. J., and Zimmerley, H. H. A survey of fertilizer application practices in connection with field crops. Conducted by the National Joint Committee on Fertilizer Application . . . 45 pp. December 1936. [Mimeographed and distributed by the National Fertilizer Association.]

Zimmerley, H. H., Bateman, Fred H., Callister, G. J., Skinner, J. J., and Cumings, G. A. A survey on planting and fertilizing the vegetable crops, made by the National Joint Committee on Fertilizer Application . . . 24 pp. September 1936. [Mimeographed and distributed by the National Fertilizer Association.]

zone from 1 inch below to slightly above the seed level. Bands 1 inch wide are satisfactory for quantities up to 200 pounds per acre. For heavier rates the width of band or the lateral separation of seed and fertilizer bands should be increased. For drilled corn the fertilizer should be evenly drilled in continuous bands in the same relative position as suggested for hill applications. The advantage of the improved depositor over the old type is evident from the data in table 4, from the Ohio Agricultural Experiment Station (*288*).

Table 4.—*Effect of improving the design of the fertilizer depositor upon the results obtained with a single make of corn planter*

Amount of 14-12-4 fertilizer all in hill (pounds)	Increase in yield over unfertilized: Old-type depositor [1]: Fertilizer in contact with seed, 1929	Increase in yield over unfertilized: Old-type depositor [1]: Fertilizer midway between hills, 1930	Increase in yield over unfertilized: Improved depositor,[2] bands at side of seed: 1931	Increase in yield over unfertilized: Improved depositor,[2] bands at side of seed: 1932
	Bushels	*Bushels*	*Bushels*	*Bushels*
100	−1.7	0.4	11.1	
200	−2.3	−2.4	16.9	[3] 19.9
300	−18.0	−.1	13.9	28.8
400	−29.1	−3.7	21.4	

[1] No deflector or hood.
[2] Deflector and hood.
[3] 150 pounds per acre on this plot.

Potatoes

Extensive studies under a wide range of conditions show that fertilizer is best applied in two bands, approximately 2 inches wide, placed on each side, 2 inches from and about level with the lower plane of the seed piece. Figure 2 illustrates how this placement is obtained with a modern potato planter. Its superiority to other methods in common use is shown by the data in table 5 (*49*).

Table 5.—*Average yields from different methods of applying fertilizers to potatoes*

State	Period	Average yields with fertilizer placed—: At sides of seed piece [1]	Average yields with fertilizer placed—: Band under seed piece [2]	Average yields with fertilizer placed—: Mixed in row [3]
	Years	*Bushels*	*Bushels*	*Bushels*
Maine	4	392	357	349
Michigan	5	203	188	177
New Jersey	5	274	230	250
Ohio	4	238	226	225
Virginia	4	248	215	228

[1] In side bands, 2 inches from and slightly below level of seed piece.
[2] In band, 4 to 5 inches wide, approximately 1 inch directly below seed piece.
[3] In row, well mixed with soil throughout cross-sectional area about 5 inches wide and 2 inches deep, with seed piece located at the center.

Cotton

Fertilizer-placement experiments conducted throughout the Cotton Belt from North Carolina to Texas during the years 1930–35 showed consistently that fertilizer applied at time of planting gave best results when placed in bands located

in a zone 1½ to 3½ inches to each side and 1 to 3 inches below the level of the seed. A combination cotton planter and fertilizer distributor designed to give this type of placement is shown in figure 3. The average results of experiments conducted in 1936 at Rocky Mount, N. C., Columbia and Clemson College, S. C., and Tifton, Ga., comparing side placement of fertilizer both at planting time and 10 days before planting with three other methods in common use are shown in table 6.[14]

FIGURE 3.—Combined cotton planter and fertilizer distributor. Fertilizer placed in 2-inch bands, 2½ inches from seed and at any desired depth.

Table 6.—*Yield from side placement compared with that from other methods of applying fertilizer to cotton* [1]

Method of application (600 pounds 6-8-4 per acre)	Yield per acre	Increase
	Pounds	*Pounds*
No fertilizer	638	-------
Band 2 inches under seed at planting [2]	787	149
Band 3 inches under seed 10 days before planting [2]	971	333
Mixed with soil under seed before planting [2]	1,073	435
Bands 3 inches each side, 3 inches below seed level, at planting	1,191	553
Bands 2½ inches each side, 3 inches under seed, 10 days before planting	1,275	637

[1] Results are averages for experiments at 4 locations in 1936.
[2] Common farm practice.

Tobacco

Row application has been found generally preferable to broadcasting except in the Connecticut Valley where exceptionally heavy applications—more than 1½ tons per acre—are the rule. Fertilizer-placement tests in progress for 4 years in the South Atlantic States have shown that a narrow band of fertilizer applied at time of transplanting about 2½ inches to each side of the row and on a level 1 inch

[14] CUMINGS, et al. See footnote 10, p. 555.

below the root crown has usually been most effective. In some instances, applying part of the fertilizer in this position and the remainder as a delayed side dressing along the row has proved superior to applying the full amount at planting. Average results from these two methods compared with two other common methods of application from experiments at Oxford, N. C., Florence, S. C., and Tifton, Ga., in 1935 and at Upper Marlboro, Md., in 1934 are shown in table 7.[15] Transplanters equipped with fertilizer depositors for applying the fertilizer at the side of the row are available commercially.

Table 7.—*Yield from side placement compared with that from other methods of applying fertilizer to tobacco* [1]

Method of application	Average yield per acre	Value per acre
	Pounds	*Dollars*
Drilled in row, mixed and ridged [2]	1,422	277
Mixed with soil around plant	1,214	235
Bands 2½ inches on both sides and 1 inch below root crown	1,523	307
Three-fifths at side at planting, two-fifths as side dressing later	1,544	320

[1]Average results from experiments at Oxford, N. C., Florence, S. C., and Tifton, Ga., in 1935 and at Upper Marlboro, Md., in 1934.
[2]Prevailing method on farms.

Sugar Beets

Seasonal and soil conditions appear to influence considerably the comparative returns from different methods of fertilizer application. However, row application is generally superior to broadcast, and, in the row, the fertilizer should be placed relatively near the seed and at such a depth below seed level that it will not be disturbed in blocking. Average yields obtained in Michigan experiments [16] including four locations in 1934, and three each in 1935 and 1936, with 300 pounds 2-12-6 applied in the row at planting were: (1) Fertilizer in bands 1½ inches to each side and 1¾ inches below seed level, 11.1 tons; (2) in one band 1¾ inches directly below seed, 10.0 tons; (3) in direct contact with seed, 10.4 tons; (4) no fertilizer, 8.5 tons.

Small Grains

Applying the fertilizer at time of planting through the fertilizer attachment of the grain drill, which places the fertilizer close to and in partial contact with the seed, has been found superior to separate applications, either broadcast or drilled. Side-band application has not been investigated. However, owing to the large number of seed sown in comparison with the final stand of plants required for maximum yields, and the stooling of these crops, some sacrifice of plants from fertilizer contact is probably less objectionable than with most crops.

Established Meadows and Pastures

Grass meadows and pastures are often treated with straight mineral nitrogen fertilizers, in which case mere surface broadcasting is as effective as any method of subsurface incorporation. With fertilizers containing phosphoric acid and potash, which penetrate slowly if applied on the surface, applications to meadows are probably best made through the fertilizer attachment of a disk grain drill used at a time when soil conditions will permit incorporation to a depth of 1 to 2 inches. However, recent experiments indicate that surface broadcasting may be superior on bluegrass pastures.

[15]McMurtrey, J. E., Jr. summary of fertilizer placement experiments with tobacco in the southeastern states. Natl. Joint Com. Fert. Appl. Proc. 10: 107-112. 1934. [Mimeographed.]
——— fertilizer placement experiments with tobacco in the southeastern states. Natl. Joint Com. Fert. Appl. Proc. 11: 37-42, illus. 1935. [Mimeographed.]
[16]Cook, R. L., Millar, C. E., and Davis, J. F., the effect of fertilizer placement and rate of application on the yield and stand of sugar beets at the michigan experiment station. Natl. Joint Com. Fert. Appl. Proc. 10: 104-106; 11: 83-87; 12. 102-105. 1934-36. [Mimeographed.]

Soybeans, Cowpeas, Field Beans, and Cannery Peas

These crops are all highly sensitive to fertilizer injury, hence placements of fertilizer in contact with the seed are especially to be avoided. In cases where these crops are planted with a common grain drill, the fertilizer should be broadcast or drilled in as a separate operation from seeding. To date such drills are not equipped for side placement of fertilizer, although the results obtained with an experimental drill with cannery peas at the New York State Station, presented in table 8 (data from (*338*)), indicate the need for such improvement.

Table 8.—*Effect of fertilizer placement on yield of cannery peas in 1935, Geneva, N. Y.*

Fertilizer placement (300 pounds 4-16-4)	Stand	Yield per acre vined peas	Loss or increase
	Percent	*Pounds*	*Pounds*
With seed	60	935	−1,311
Above seed	94	2,204	−42
2½ inches to side and 1 inch below seed level	99	2,877	+631

Where these crops are planted with a special bean drill, or with corn or beet planters, fertilizer distributors providing for side-band placement are available. Preliminary experiments indicate that the bands are best placed 1½ to 2½ inches to the side and 1 to 1¾ inches below the seed level.

Vegetable Crops

Proper placement of fertilizer for vegetable crops is of special importance owing to their high acre value and to the fact that poor stands and the delay in germination and early growth associated with improper placement may so influence the earliness and uniformity of the product as greatly to reduce its value. Space prevents individual consideration of the vegetable crops. However, experiments with lima and snap beans, spinach, kale, carrots, peas, onions, celery, tomatoes, cabbage, and sweetpotatoes, chiefly in New York, Virginia, and Florida, indicate that in most cases applying all of the fertilizer in side bands at planting or applying part in this position and the remainder as a delayed side dressing in a similar position gives best results. For some of these crops, including those commonly transplanted, machines are available for planting and applying the fertilizer in the proper position in one operation. For some crops planted in closely spaced rows—spinach, lettuce, etc.—similar machines are not yet available.

THE AUTHOR *of this article first shows that in general not nearly as much lime is used in the humid portions of the United States as should be used for the good of the soil. He tells what he considers to be the chief obstacle to greater use and gives broad recommendations for "balancing the lime budget." The rest of the article considers scientific and technical aspects of liming—the relation of soil reaction to plant growth, the nature and use of rapid chemical tests, and the nature and functions of the acids in the soil.*

Soil Acidity and Liming

By Emil Truog [1]

LIME in the form of marl, chalk, or limestone is so widely and profusely distributed the world over, and the benefits derived from its use on many soils are so favorable and striking, that liming of land was probably practiced, from time to time, long before present-day records make note of it. Records show definitely that liming of land was practiced before the Christian Era. It seems strange, then, that the practice should have lagged in this country, so that even in recent times it is not as widespread as would be desirable. There is a good reason for this, however. Only within recent times have satisfactory methods and adequate scientific knowledge been available for determining the actual need for and proper use of lime in soil management, to say nothing of an adequate medium for interpreting and extending the information to the farmer.

In this country, the practice of liming land was tried in a few isolated cases in colonial times. During the nineteenth century the practice grew quite extensively for a time and in a few localities, but for the most part, except in Pennsylvania, never became a permanent general practice. Edmund Ruffin (1794–1865), a practical farmer of Virginia, was probably the first man to test soils in this country and to surmise or recognize the general prevalence of acidity in upland mineral soils. He conducted extensive field experiments with lime and wrote a comprehensive treatise on calcareous manures (*327a*).[2] In the closing years of the century, Wheeler, at the Rhode Island Agricultural Experiment Station, made the positive demonstration that many upland mineral soils are distinctly acid and need lime (*454a*), which was the beginning of a sustained appreciation in this country of the need and value of lime in agriculture.

[1] Emil Truog is Professor of Soils at the University of Wisconsin.
[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Today liming of the land is accepted as a fundamental and necessary practice by all who are well informed in the matter. It is not too much to say that it must be the very backbone of profitable crop production, soil conservation, and permanent agriculture in the humid regions of this country. While we still need to improve our chemical tests and methods for soil reaction, study further the function and action of lime in soils, and more accurately measure the rate of loss of lime under varying conditions, it is nevertheless safe to say that enough scientific and practical knowledge is now at hand to lend confidence and stability to the practice of liming land.

Only one reason for the backward status of liming remains—the

FIGURE 1.—Producing agricultural lime for local use with a portable grinder. This method has given farmers in many sections their basic soil-building material at a low figure.

high cost of lime. Limestone and marl are among the most plentiful of materials in the earth's crust; machinery and cheap power are at hand for mining and grinding (fig. 1); transportation facilities are already good and are rapidly becoming better; it is known where lime is needed and how it should be used to insure satisfactory results; and finally, when lime has been made cheaply and easily obtainable through special agencies, farmers have used it in amounts approximating those needed.

Why did Kentucky, in 1936, use the equivalent of 124 pounds of lime oxide per acre of cropland and Tennessee only 8½ pounds, and similarly, in the same year, Wisconsin 64 pounds and Michigan only 14 pounds? The climate, need of lime, and natural supplies of lime in the pairs of States compared are quite similar. All of these States have extension services which for a long time have been offering infor-

mation on the subject through demonstrations, publications, and lectures. Evidently that method alone will not do the job. Until the extension services are able to form some connection with a large-scale organization, either private or governmental, that can be depended upon to furnish the farmer this basic and fundamental soil-building material—lime—at a reasonably low price, or some other equally effective method is found and adopted, permanent soil improvement and soil conservation will remain, to a large degree, "a pot of gold at the end of the rainbow."

BALANCING THE LIME BUDGET

There is still a lack of definite information regarding the rate of loss of lime brought about by cropping and leaching and the length of time that a dose of lime is amply effective. The rate of loss through leaching in the North Central States appears to be less than was formerly believed. High evaporation and effective use of water by cropping tend to cut down this loss greatly. Alfalfa, in particular, having a high water requirement, growing from early spring to late fall, and drawing both lime and water from a great depth, should, when it occupies the land, tend to cut the loss by leaching to a minimum. In this case, unless the annual rainfall be considerably more than 30 inches, the loss is probably restricted almost entirely to what the alfalfa plants take, and in livestock farming this can be partly returned in the form of manure.

For general farming in the North Central States, it may be conservatively estimated that the annual loss of lime (in terms of calcium carbonate) above what is returned in manure and crop residues ranges between 100 and 500 pounds per acre. Farther south, where the rainfall is heavier, and east, where evaporation is less, the loss may in many cases be greater. For the North Central States, where the great bulk of the lime is now used, a 2-ton application of ground limestone per acre should in most cases take care of the total net loss over a period of 10 to 20 years.

Table 1, prepared by the National Lime Association, gives a summary of the annual lime consumption, total and pounds per acre, on cropland in the United States by States and regions for the years 1929–36. The data disclose some interesting and very important information. First of all, it is seen that the Midwestern States take about three-fourths of the total national consumption. If the data giving the amount used per acre of cropland are taken as a basis of comparison, a much better picture of the situation is obtained. These data show that only in recent years is the consumption in the Midwestern States as a whole approaching that of the New England States and Mid-Atlantic States. The amount used in Pennsylvania has been very consistent over this period of years. This State was a pioneer in the use of lime in colonial times, and the practice has undoubtedly become ingrained in the minds of the better farmers there. The lasting influence in Illinois of C. G. Hopkins (fig. 2), the foremost advocate of lime in the Midwestern States during the first quarter of the century, is shown in the Illinois figures for the period. The amount of lime used in some of the Southern States is very small indeed.

Table 1.—*Eight-year summary of liming material[1] consumption on United States farms, and resultant quantity of effective lime oxides applied per acre of cropland, by States and regions, 1929–36*

State and region	1929		1930		1931		1932	
	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]
	Tons	*Pounds*	*Tons*	*Pounds*	*Tons*	*Pounds*	*Tons*	*Pounds*
Maine	8, 343	5. 1	8, 764	6. 6	8, 289	7. 1	4, 808	4. 1
New Hampshire	5, 500	10. 5	5, 500	10. 5	5, 500	13. 1	4, 100	9. 8
Vermont	8, 601	8. 0	7, 268	7. 0	4, 702	4. 5	3, 632	3. 6
Massachusetts	56, 336	93. 0	56, 336	93. 0	66, 000	138. 3	46, 009	95. 8
Rhode Island	1, 276	21. 1	1, 276	21. 1	2, 812	55. 1	1, 350	24. 4
Connecticut	27, 500	53. 4	27, 500	53. 4	22, 000	53. 0	35, 000	85. 8
New England	107, 556	25. 6	106, 644	25. 6	109, 303	31. 2	94, 899	26. 6
New York	185, 000	21. 6	191, 650	22. 5	166, 800	21. 7	110, 922	14. 8
New Jersey	48, 336	56. 2	58, 293	68. 4	52, 478	69. 6	35, 151	45. 6
Pennsylvania	255, 178	36. 2	242, 275	35. 2	213, 480	32. 8	186, 881	28. 8
Delaware	17, 170	48. 7	16, 562	46. 4	10, 382	30. 5	5, 812	16. 5
Maryland	28, 848	18. 2	36, 049	23. 2	40, 060	26. 6	28, 803	19. 3
West Virginia	13, 430	7. 7	10, 023	5. 6	9, 398	5. 7	2, 256	1. 5
Mid-Atlantic	547, 962	27. 7	554, 852	28. 5	492, 598	27 2	369, 825	20. 6
Ohio	237, 381	21. 3	232, 920	20. 8	168, 073	15. 7	102, 579	9. 7
Indiana	204, 132	17. 4	164, 777	13. 8	102, 530	9. 3	115, 913	9. 3
Illinois	950, 000	31. 2	750, 000	24. 6	325, 000	10. 7	139, 522	4. 6
Kentucky	306, 000	45. 8	294, 000	42. 1	229, 000	32. 5	175, 437	24. 7
Michigan	111, 102	9. 8	135, 984	11. 7	127, 942	12. 8	148, 113	12. 6
Wisconsin					132, 489	12. 1	116, 623	11. 4
Minnesota	17, 940	. 9	17, 450	. 8	12, 000	. 5	6, 560	. 3
Iowa	350, 000	11. 1	350, 000	11. 8	227, 727	9. 0	142, 089	5. 7
Kansas	43, 375	1. 8	39, 025	1. 6	42, 500	1. 4	20, 050	. 7
Missouri	236, 897	15. 5	228, 404	14. 9	175, 000	11. 2	168, 431	6. 9
Midwestern	2, 456, 827	14. 6	2, 212, 560	13. 3	1, 542, 261	9. 0	1, 075, 317	6. 3
Virginia	120, 000	25. 8	114, 000	24. 5	64, 984	14. 0	47, 557	10. 5
North Carolina	100, 000	14. 6	100, 000	14. 7	54, 290	5. 0	44, 702	6. 5
South Carolina			12, 000	2. 4	8, 662	1. 7	7, 880	1. 5
Georgia			5, 085	. 5	6, 348	. 6	6, 321	. 6
Florida	7, 000	4. 4	3, 500	2. 2	5, 064	3. 0	8, 694	4. 9
Tennessee	350, 000	46. 1	332, 500	43. 8	225, 000	29. 3	155, 000	20. 3
Alabama			10, 700	1. 4	4, 575	. 5	5, 289	. 6
Mississippi	10, 000	1. 6	10, 000	1. 6	6, 000	. 8	2, 367	. 3
Arkansas and Louisiana			5, 000	. 7	1, 800	. 2	723	0
Southern	587, 000	21. 3	592, 785	10. 3	376, 723	6. 0	278, 533	4. 4
California	31, 022	2. 6	21, 155	2. 3	16, 756	1. 8	10, 041	1. 0
Oregon	2, 000	. 5	2, 000	. 5	2, 800	. 6	2, 600	. 6
Washington	4, 000	. 7	8, 300	1. 3	8, 500	1. 3	8, 500	1. 3
Western	37, 022	2. 0	31, 455	1. 5	28, 056	1. 4	21, 141	1. 0
Grand total	3, 736, 367		3, 498, 296		2, 548, 941		1, 839, 715	

[1] Liming materials consist of ground limestone, limestone screenings and meal, burned and hydrated lime, marl, and miscellaneous materials.

[2] More specifically, this means the pounds of effective lime oxides per acre of cropland, computed on the basis of 35 percent for limestone screenings and farm-dug marl, 50 percent for ground limestone, miscellaneous materials, and commercial marl, 70 percent for hydrated lime, and 85 percent for burned lime.

In Wisconsin the use was low and the rise in consumption slow until the mining and grinding of liming materials was taken up by various work-relief programs, starting in 1934. This made cheap lime for

Table 1.—*Eight-year summary of liming material consumption on United States farms, and resultant quantity of effective lime oxides applied per acre of cropland, by States and regions, 1929–36*—Contd.

State and region	1933		1934		1935		1936	
	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]	Liming materials	Oxides per acre [2]
	Tons	*Pounds*	*Tons*	*Pounds*	*Tons*	*Pounds*	*Tons*	*Pounds*
Maine	5, 650	5. 1	7, 519	7. 3	5, 731	5. 1	23, 598	17. 6
New Hampshire	1, 500	3. 5	2, 196	5. 4	2, 220	4. 8	5, 700	12. 3
Vermont	5, 280	5. 1	2, 369	2. 4	5, 716	5. 9	14, 659	14. 7
Massachusetts	40, 433	86. 1	25, 902	50. 5	25, 220	44. 9	34, 612	59. 0
Rhode Island	1, 127	20. 5	2, 544	45. 4	1, 935	30. 2	2, 690	41. 5
Connecticut	10, 000	25. 1	19, 996	46. 2	24, 061	45. 4	30, 975	29. 4
New England	63, 990	18. 7	60, 526	16. 8	64, 883	16. 7	112, 234	27. 9
New York	106, 070	14. 3	99, 115	13. 2	122, 371	16. 2	224, 796	28. 7
New Jersey	33, 751	43. 6	39, 541	51. 3	50, 246	62. 0	64, 397	75. 0
Pennsylvania	148, 146	23. 8	160, 844	25. 2	245, 084	39. 9	307, 760	46. 5
Delaware	4, 751	13. 4	9, 637	27. 6	8, 902	24. 7	12, 820	35. 0
Maryland	34, 091	22. 6	26, 923	17. 6	48, 146	31. 1	87, 853	57. 6
West Virginia	4, 544	3. 3	16, 474	9. 7	15, 260	10. 2	31, 613	18. 6
Mid-Atlantic	331, 353	19. 0	352, 534	19. 8	490, 009	28. 1	729, 239	39. 6
Ohio	121, 593	11. 3	157, 711	12. 7	176, 168	14. 0	318, 959	22. 5
Indiana	110, 974	7. 8	156, 446	11. 5	253, 511	18. 0	466, 286	38. 6
Illinois	184, 338	6. 1	333, 878	11. 0	356, 095	11. 8	1, 022, 916	33. 9
Kentucky	174, 650	24. 6	165, 800	23. 7	284, 992	40. 7	869, 218	123. 9
Michigan	138, 086	11. 6	250, 277	21. 0	169, 784	12. 8	184, 868	13. 9
Wisconsin	82, 569	7. 9	373, 305	34. 1	764, 963	65. 0	682, 837	64. 0
Minnesota	4, 750	. 2	7, 450	. 4	13, 000	. 6	10, 169	1. 8
Iowa	120, 525	5. 0	177, 400	7. 4	224, 016	10. 5	902, 689	42. 5
Kansas	13, 900	. 5	34, 060	1. 2	13, 373	. 3	34, 460	. 9
Missouri	59, 991	3. 8	90, 713	5. 2	122, 519	8. 3	406, 533	27. 8
Midwestern	1, 011, 376	5. 8	1, 747, 040	9. 7	2, 378, 421	12. 6	4, 928, 935	27. 0
Virginia	70, 668	15. 3	81, 985	17. 2	110, 636	22. 9	196, 140	41. 2
North Carolina	38, 456	5. 6	59, 460	8. 6	75, 861	10. 5	94, 254	12. 5
South Carolina	16, 302	3. 2	28, 210	5. 6	42, 266	8. 0	48, 146	9. 1
Georgia	7, 236	. 7	5, 526	. 5	14, 020	1. 3	16, 714	1. 5
Florida	11, 002	6. 0	16, 856	9. 2	35, 041	16. 5	42, 748	18. 0
Tennessee	43, 475	5. 7	27, 873	3. 5	27, 698	3. 5	64, 383	8. 5
Alabama	6, 914	. 8	14, 801	1. 8	19, 042	2. 2	19, 749	2. 3
Mississippi	1, 757	. 2	3, 065	. 4	4, 075	. 5	4, 263	. 5
Arkansas and Louisiana	------	------	------	------	------	------	6, 543	1. 4
Southern	195, 810	3. 9	237, 776	4. 6	328, 639	6. 1	492, 940	9. 2
California	13, 590	1. 6	23, 853	2. 6	16, 374	1. 9	23, 308	2. 8
Oregon	2, 438	. 6	3, 862	1. 1	5, 213	1. 2	10, 020	2. 4
Washington	8, 500	1. 3	8, 250	1. 1	8, 250	1. 2	8, 750	1. 0
Western	24, 528	1. 3	35, 965	1. 8	29, 837	1. 5	42, 078	2. 2
Grand total	1, 627, 057	------	2, 433, 841	------	3, 291, 789	------	6, 305, 426	------

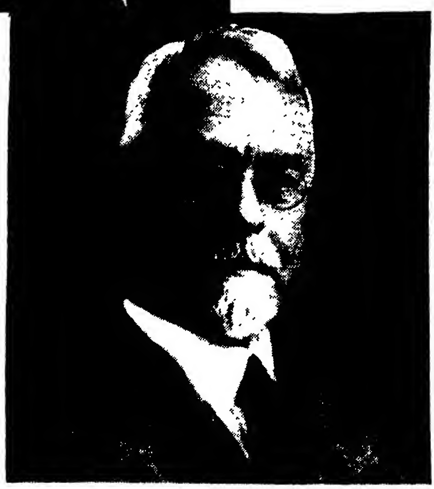
[2] More specifically, this means the pounds of effective lime oxides per acre of cropland, computed on the basis of 35 percent for limestone screenings and farm-dug marl, 50 percent for ground limestone, miscellaneous materials, and commercial marl, 70 percent for hydrated lime, and 85 percent for burned lime.

agricultural purposes a reality for the first time in the history of the State. The effect was like magic. It immediately increased the consumption five or six times, even though the depression was still much in evidence.

The data in table 1 allow us to arrive at some sort of answer to the

W. Frear, Pennsylvania Agricultural Experiment Station 1885–1922, compiled the [illegible] comprehensive bulletin in the United States on the use of agricultural lime for acid soils. Pennsylvania was the pioneer State in the general use of agricultural lime.

C. G. Hopkins, Illinois Agricultural Experiment Station 1894–1919, was foremost advocate of liming in the North Central States during the first quarter of the nineteenth century, and as a result Illinois has long been a leader in the use of agricultural lime.



H. J. Wheeler, Rhode Island Agricultural Experiment Station 1889–1912, pioneer American investigator of soil acidity and liming, was the first to demonstrate the general prevalence of an injurious degree of acidity in upland mineral soils of the eastern United States.

FIGURE 2.—Leaders in the field of soil acidity and liming.

question: How close are we coming to balancing the lime budget on our cropland? It was previously stated that under general farming conditions in the North Central States, the annual loss of lime, in terms of calcium carbonate, above what is returned in manure and crop residues, is 100 to 500 pounds per acre. In terms of calcium oxide, these figures become approximately 50 to 250 pounds, since 56 pounds of the oxide equals 100 pounds of the carbonate. Comparing, now, the annual loss of 50 to 250 pounds of calcium oxide per acre with the annual return per acre of cropland given in table 1, it will be seen that the lime budget is for the most part far out of balance. It is doubtful if any of the States, even in the years of their highest use of lime, have balanced their lime budget.

A conservative estimate indicates that it would take approximately 15,000,000 tons of ground limestone to bring the cropland in Wisconsin to a satisfactory lime level. After this initial application, it would then take approximately 1,000,000 tons annually to maintain this level. Even with the rapid strides Wisconsin has made in recent years under work-relief programs, there is still a long way to go to balance the lime budget.

The actual annual cost per acre involved in balancing the lime budget is, after all, much lower than ordinarily assumed. The cost of an initial application should be spread over the period of years for which it will balance the loss. Since a ton of ground limestone, costing in some North Central States approximately $2 will balance this loss for a period of 5 to 10 years, the annual cost per acre becomes 20 to 40 cents. Data from experiments and demonstrations are at hand, almost without end, showing that this cost is insignificant compared to the increased production and the soil improvement that result.

PRACTICAL USE OF LIME

Not only the Federal Government but practically every State in the humid region of the United States now has several bulletins or pamphlets, and other popular material, on the practical aspects of liming land. The various forms of lime and methods of applying them are well known and are adequately discussed in these popular publications, and little need be said here about them.

A few words may be in order relative to the amounts of lime that should be used in specific cases. In the first place, at least one surface-soil sample from each acre of a field in question should be taken and tested for acidity by one of the methods to be described later. One or more subsoil samples from a depth of 4 feet or more may also be taken to advantage from each field. Fields usually vary greatly from place to place as regards degree of acidity. Often when the whole field is given a uniform dose of lime, some parts get too little and others more than is necessary. This leaves the field ununiform and gives less satisfactory results than are otherwise possible. After a field has been properly sampled and tested, a soil-reaction map may be made of it, and lime applied accordingly. Circular 346 of the Illinois Station (*219*) discusses in detail the preparation and use of soil-acidity maps for this purpose.

The amount of lime to be used, usually ranging from 2 to 5 tons per acre of ground limestone, depends primarily on the degree of

acidity of the soil, buffer capacity of the soil, and crops to be grown. Under most general farming conditions in the Northern States, it is advantageous to regulate the application of lime so that the reaction of the soil will be maintained nearly at the neutral point, or close to pH 6.5.[3] At or near pH 6.5 alfalfa and clover grow very satisfactorily, their root nodule bacteria persist well, and conditions are favorable for a satisfactory availability of phosphorus, iron, manganese, and possibly copper, zinc, and boron. At this point, a satisfactory granulation of the soil is also achieved, unless the soil is very heavy, when more lime (burned lime is here most effective) and a higher pH value (greater alkalinity) may be desirable. Under other farming conditions and in special cases, it is, of course, often advantageous to regulate the lime supply so as to maintain either a higher or lower pH than 6.5.

Tables and charts are supplied with various soil-testing outfits indicating approximately the amount of lime needed to bring a certain class of soil of a certain pH value up to whatever pH value may be desired. Because of the usual variation in acidity from place to place in a field, the quality of the liming materials commonly used, and practical difficulties in controlling the rate of application, this method of arriving at the amount of lime to be applied is sufficiently accurate for practical purposes. To test a number of soil samples from a field by a simple method is much more to the point for ordinary practical purposes than to test one or two samples by a more accurate but time-consuming method.

RELATION OF SOIL REACTION TO PLANT GROWTH

Why is it necessary to control the acidity of the soil by the use of lime?

The relation of soil reaction to the growth of plants is so complex that a great deal of confusion has arisen as to just how reaction influences growth. Extensive lists of plants have been published (*150, 158, 210, 414, 454*) giving the reaction range most favorable for their growth. A very complete bibliography of this subject and related matters was published by Arrhenius (*19*) in 1926. In artificial cultures, it is possible to control the conditions fairly well, so that only the direct influence of reaction limits growth. The indirect and direct influences of reaction on plant growth in soil cultures may be summarized as follows:

The indirect influence of reaction on plants is through the effects of reaction on—

(1) Physical condition of the soil.
(2) Availability of essential elements.
(3) Activity of soil micro-organisms.
(4) Solubility and potency of toxic agents.
(5) Prevalence of plant diseases.
(6) Competitive powers of different species of plants.

The direct influences of reaction on plants are—

(1) In extreme acidity or alkalinity, a toxic or destructive effect on plant tissues of excess of hydrogen (acid) or hydroxyl (alkaline) ions.

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[3] The neutral point is 7.0. See Glossary, p. 1173.

(2) An unfavorable balance between the acidic and basic constituents available for absorption by plants.

Indirect Influence of Reaction on Plants

The physical condition of clay soils is known to be affected unfavorably by an acid condition, because of an insufficient supply of calcium bicarbonate in the soil solution to keep the base exchange material well saturated with calcium and the clay particles coagulated (flocculated) [4]—a condition that is necessary for the highly desirable granular or crumb structure. In sandy soils the presence of lime carbonate probably improves the physical condition by acting as a binding agent. In improving the physical condition of soils in these ways, the presence of lime carbonate thus indirectly helps in the proper regulation of the air and moisture supply of soils, which in turn is the fundamental basis for developing their proper biological and chemical activity. Both a highly acid or a highly alkaline condition may, by inducing separation of the colloidal particles (deflocculation), cause a movement of valuable colloidal material from the surface soil into the subsoil where it may be precipitated in the form of a detrimental hardpan.

The availability of all of the essential elements obtained by plants from the soil is affected in one way or another by the reaction of the soil. Phosphorus in particular becomes less available as the pH value drops below 6.5 to points of greater acidity.[5]

The influence of reaction on the availability of potassium is not very clearly understood as yet and needs further study. With increasing acidity, calcium and magnesium become less available to plants because of a decreasing supply and a greater competition for them by the hydrogen-saturated exchange acids.[6] Iron, manganese, copper, zinc, and possibly boron appear to become less available when the pH value rises above the neutral point (pH 7), and this may limit plant growth in certain cases, especially when the soil is sandy and low in organic matter. This lowering in availability of certain elements may explain the unfavorable results occasionally reported from liming. This needs further study.

The activity of many soil micro-organisms is greatly retarded by an acid reaction, and this in turn affects the availability of the nitrogen, sulphur, and other elements whose liberation is dependent on the decomposition of organic matter brought about by the micro-organisms. Many species of the nitrogen-fixing bacteria are especially sensitive to acidity and can exist for only a comparatively short period in distinctly acid soils. The root nodule bacteria of alfalfa and sweetclover do not persist well in a soil when its pH value is below 6.5. High acidity may bring about toxic concentrations of iron and aluminum salts, and in very special cases copper and zinc salts.

Certain fungous diseases, such as finger-and-toe, develop to a harmful extent only in acid soils, while other plant diseases, the potato scab, for example, are much more serious when the pH value rises above 5.3, although the potato plant itself grows better when there is less

[4] See Glossary, p. 1167.
[5] In many cases this is due to the interaction of phosphates with hydrated iron oxides to form a basic iron phosphate, there being an insufficient concentration of calcium bicarbonate in the soil solution to retard this.
[6] See General Chemistry of the Soil, p. 911.

acidity (a higher pH value). Aside from the cases known to have a direct relation to plant diseases, there are a few special plants, such as the cranberry, blackberry, and watermelon, for which a soil of at least slight acidity seems desirable and in some cases necessary for the best growth. It is not known just why these plants grow better on an acid soil, but it seems possible that in some cases plant diseases, or malnutrition due to a lack of iron or some minor essential element, may again be factors.

When for some special reason, like the control of potato scab or the growth of an acid-loving plant, it is desired to make the soil more acid, sulphur, sulphuric acid, aluminum sulphate, or iron sulphate may be used. Of these sulphur is used most commonly. It takes several weeks for the sulphur to become oxidized in the soil to sulphuric acid through the action of sulphur-oxidizing bacteria, and if these are not already present in the soil, an inoculated sulphur mixture should be used. In calculating how much sulphur may be needed, it should be remembered that 1 pound will neutralize about 3 pounds of calcium carbonate. If immediate action is desired for small-scale purposes, one of the other materials mentioned may be used.

The influence of soil acidity or alkalinity on the competitive powers of different species of plants for establishing themselves and crowding out others is exemplified in the case of common sorrel, which grows best on neutral soils but is usually found on acid soils because it cannot compete with others under neutral conditions. Under native conditions, or where land is left in meadow or pasture for a considerable number of years, this influence may be a factor of considerable importance. However, under most farming conditions, this form of competition is largely eliminated by rotation and cultivation.

Direct Influence of Reaction on Plants

The work of several investigators (*166*, *418*) indicates that a direct toxic or destructive effect of an excess of hydrogen ions (acid) or hydroxyl ions (basic or alkaline) on root tissues probably does not take place except at extreme acidity or alkalinity. The reaction of the root sap of most agricultural plants falls in the acid pH range of 4 to 6, indicating that plant tissues are so constituted as to stand the acidities ordinarily found in soils. Extreme hydroxyl-ion concentrations, such as are represented by a pH value greater than 9, probably have a direct toxic effect in many cases.

The balance between basic and acidic constituents available for absorption by plants varies directly with the reaction of soils and is probably the most important factor involved in the relation of soil reaction to plant growth. In neutral soils the active basic constituents are just equal to the active acidic constituents. In an acid soil the acid constituents are in excess, and in an alkaline soil the basic constituents are in excess.

It is obvious that if plants were dependent entirely on the soil solution for their needs of essential elements from the soil, and if the bases and acids were absorbed in the proportion existing in the soil solution, an excess of acids over bases would be absorbed in the case of acid soils. This might be more favorable for one species of plant than another, depending on the proportion of acids to bases required by the plant

in its metabolism. An examination of the composition of different species of plants as regards their basic and acidic constituents should throw some light on this matter.

In the case of alfalfa, it is found that it must obtain from the soil the equivalent of almost twice as much of the bases as of the acids, if, as is often the case, it takes two-thirds of the nitrogen needed from the air. As a consequence nearly one-half of the bases should enter in the form of the carbonate or bicarbonate.

A base entering as the carbonate or bicarbonate is for metabolic purposes a free base, because of the weakness of carbonic acid. In contrast to this, the timothy plant requires the equivalent of approxi-

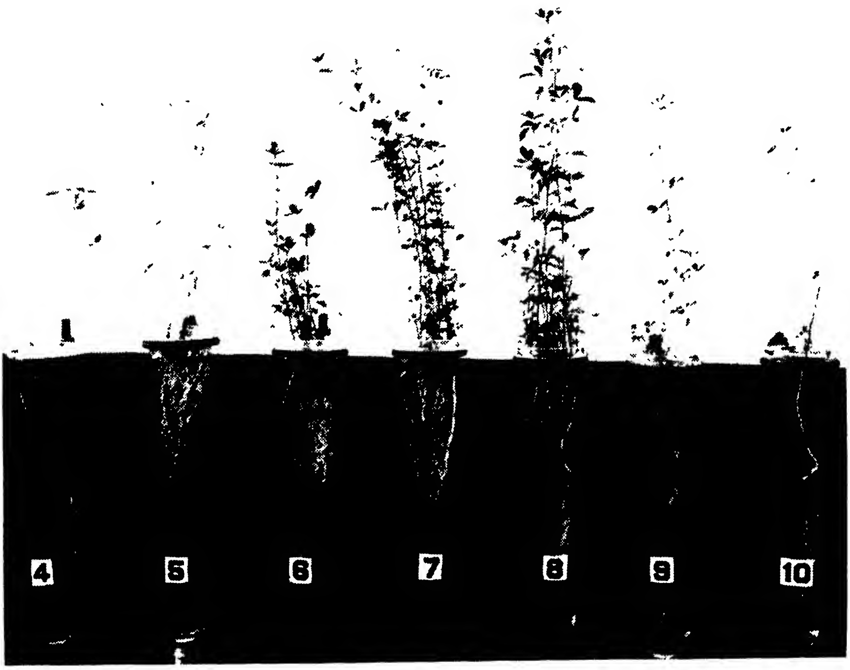

FIGURE 3.—Growth of alfalfa in sand cultures at reactions (pH values) indicated by the numbers on the vessels.

mately twice as much of the acids as of the bases, and hence none of the bases need enter in the form of the carbonate or bicarbonate. Alfalfa is known to be much more sensitive to acidity than timothy, and these data offer an explanation of this based on the metabolic requirements of the plants.

An explanation is also offered as to why alfalfa and other legumes dependent on nitrogen fixation by symbiotic bacteria [7] are affected more by acidity than plants that draw their nitrogen from the soil. When nitrogen is taken from the soil as nitrate, it brings along with it a certain amount of base. When it is taken from the air, no bases

[7] See Fauna and Flora of the Soil, p. 940.

come with the nitrogen and this must be compensated for by the intake of just that much more calcium bicarbonate.

On the basis of this explanation, the capacity of plants to feed locally on particles of limestone, feldspar, the base-exchange compounds, and other minerals, and in some cases in the deeper, less acid, and even calcareous subsoils, determines to some extent the ability of the plants to grow in acid soils. How plants may feed locally, independently of the soil solution, has been discussed by the writer (*416*) and referred to as "solid phase feeding." This does not mean that solid particles are absorbed by plants, but that through plant intervention solid material is brought into solution and subsequently absorbed.

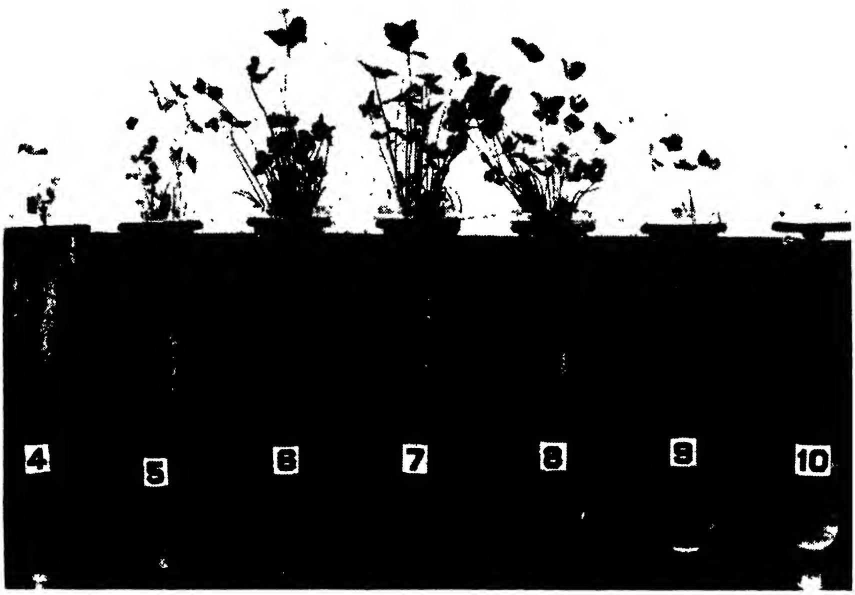

Figure 4.—Growth of red clover in sand cultures at reactions (pH values) indicated by the numbers on the vessels. Compare with figure 3 and note that both plants grow best in the reaction range pH 6 to 8 (near the neutral point), but that alfalfa does somewhat better than clover in the alkaline range (pH 7 to 10) and clover somewhat better than alfalfa in the acid range (pH 7 to 4).

Most Favorable Reaction Range

When plants are grown in solution or sand cultures supplied with ample nutrients, the reaction of the culture medium can be controlled and made the limiting or variable factor. Tests of this kind (*51, 52, 53*) have shown that the reaction range of pH 6 to 8 (slightly acid to slightly alkaline) is the most favorable for the common agricultural plants (figs. 3 and 4). Corn, the grains, and cowpeas grow relatively better at a more acid reaction than alfalfa and red clover; and alfalfa does better at a more alkaline reaction than the others; but they all do best in the pH range of 6 to 8. Results with these artificial cultures confirm the observations made when plants are grown in soil

cultures, and leave no doubt that so far as the reaction of soils is concerned the most favorable range for the common agricultural plants is pH 6 to 8.

RAPID TESTS FOR SOIL ACIDITY

Early Tests

Up to 1900 apparently the only simple chemical tests used were the litmus-paper, the lackmus-paper, and the ammonia-water tests for soil acidity, and the effervescence test for carbonates. These tests in their time did much good service but left much to be desired. The litmus-paper test was used the most. Previous to Wheeler's time (1895), tests for soil acidity were scarcely used at all in this country. Wheeler (fig. 2), deplored the shortcomings of the litmus-paper test. Litmus paper often gives an indistinct color change with acid soils owing to deterioration of the paper or poor quality to start with. As a practical test, it fails to indicate degree of acidity with much if any assurance.

During the early years of the twentieth century, several tests were devised, but none of them offered much advantage over the litmus-paper test.

The Sulphide Test

In 1915, the writer (*410*) devised the sulphide test, which is fairly rapid and distinguishes five degrees of acidity as well as neutrality or alkalinity. In this test a measured amount of soil, water, calcium or barium chloride, and zinc sulphide are placed in a flask and the mixture boiled. If the soil is acid, exchange takes place between the hydrogen of the soil exchange material and the calcium of the calcium chloride, liberating an equivalent amount of hydrochloric acid. This acid then acts on the zinc sulphide and on boiling causes the expulsion of hydrogen sulphide, which is conveniently tested for by its blackening of a piece of lead acetate paper that is laid over the mouth of the flask. After a definite period of boiling, the intensity of the blackening of the paper can be taken as a measure of the degree of soil acidity on comparison with a standard chart. Recommendations as to the need of lime are then made according to the degree of acidity. The test has been widely used in this country and is still being used to a considerable extent. Because of a lack of a suitable grade of zinc sulphide, which is all-important, the test was not extensively used in foreign countries.

Colorimetric Tests

Shortly after the introduction of the sulphide test, a whole series of excellent new color indicators came into use, covering the whole acidity and alkalinity range met with in soils and biological systems. These, with the coming into general use of the hydrogen electrode and the introduction of the pH scale by Sorensen, the Danish investigator, all at about the same time, mark by far the greatest advance that has ever been made in the testing of the reaction of soils as well as plants and all other biological systems. These developments made it possible for the first time to determine rather accurately the reaction that the root system of a plant is subjected to when growing in a certain soil.

Armed with this new series of indicators and advanced knowledge and techniques, a dozen or so colorimetric soil-reaction tests have been devised by various investigators in different countries during the past 20 years. The writer will not attempt to appraise these tests in detail here. In the earlier tests, a water extract of the soil was usually made, and to this was added an appropriate indicator. The color of the extract was then compared with standard colors, making possible a reading of the reaction in terms of pH values.

In many of the later tests, the soil is treated directly with an indicator solution. One of the first tests of this kind was devised by Spurway (*381*) and goes under the trade name Soiltex. Various schemes are used for removing a few drops of the indicator solution so that the color it has assumed may be compared with the appropriate standards. Direct treatment of the soil with the indicator solution has a distinct advantage over first making a water extract, because it makes possible a direct cation exchange between the indicator and the exchange material of soils, as is the case in the sulphide test. It also lessens errors due to indicators that are not exactly neutral, since the indicator is thrown directly into a well-buffered system. These tests when properly made give results sufficiently accurate for practical purposes and are now used in this country more than any other class of tests.

One other test, the thiocyanate, devised by Comber (*74*) in 1920, should be mentioned. In this test a sample of soil in a test tube is shaken with an alcohol or other nonaqueous solution of thiocyanate, and the suspension is allowed to settle. The greater the acidity of the soil, the more soluble ferric iron will be present, and hence the redder will be the liquid after the soil settles, owing to the formation of ferric thiocyanate, which is red. The test works best when the soil sample is dry. With some soils lacking soluble iron the test does not give reliable results. This test is rapid and simple and has been and is extensively used in some sections of the country. A modification of the original test is sold under the trade name of "Rich-or-Poor Test."

QUANTITATIVE METHODS FOR DETERMINING SOIL ACIDITY [8]

Apparently the first report of an attempt to devise a quantitative method for determining soil acidity was made by Tacke (*392*) in 1897. Working with peaty soils he mixed calcium carbonate with a sample of the soil moistened to a paste, and then determined the carbon dioxide evolved, which was taken as a measure of the acidity present in the soil. A number of methods (*385*) based on a similar principle were proposed during the first 15 or 20 years of the twentieth century. The main objection to this type of method is the slowness and indefiniteness of the reaction involved.

In another class of methods proposed (*176*, *231*, *412*), the soil is treated with a known excess of alkaline hydroxide or bicarbonate in solution, after which the excess over what reacts with the soil acids is determined in various ways and the acidity calculated by difference.

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[8] The following pages are necessarily somewhat more technical in nature than the earlier part of this article.

These methods have been of considerable use, but some are rather cumbersome and give results of doubtful value. The Veitch (*443*) limewater method may be classed in this group. This is a cut-and-try method for determining the amount of limewater required, on evaporation with a soil sample, to give a subsequent water extract of the soil sample a slightly alkaline reaction. The method is one of the oldest and was formerly used quite extensively.

In still another class of methods, the sample of soil is treated with a neutral salt solution, thus allowing for cation exchange between the salt and exchangeable material of soils. The salt solution then becomes acid in accordance with the acidity of the exchange material. After filtration, the acidity of the salt extract is determined by titration.[9] Since the reaction involved does not go to completion, a factor is then sometimes used to calculate the total acidity of the soil. The Jones (*189*) calcium acetate method and Hopkins' (*168*) sodium chloride method are examples of this class of methods, which were formerly used quite extensively.

Attempts have been made to devise a direct titration method. A certain amount of success has been achieved in this direction. With the perfection of the glass electrode it would seem that a rapid, useful, and satisfactory titration method might be evolved. The matter deserves attention, for there is still a need for a better quantitative method.

Much attention has been given in the past 20 years to the perfection of an electrometric method for the accurate determination of the pH value of soils. The hydrogen electrode method was first used, but being rather cumbersome, was later superseded quite largely by the simpler quinhydrone method. This method was extensively used, but with a few special soils gives inaccurate results and in the alkaline range especially is none too accurate. Within recent years, the glass electrode method has reached a high state of perfection and is now accepted as the standard by the International Society of Soil Science (*80*) for the determination of the pH value of soils.

NATURE OF SOIL ACIDITY

The Adsorption Theory

During the early years of the present century, some investigators (*60, 148*) attempted to ascribe the acid reaction that some soils exhibit to the phenomenon of adsorption rather than to the presence of actual acids. The extensive surface on the fine or colloidal material of soils was supposed to have more attraction (physical attraction) for the base (cation) of salts than for the acid radical (anion),[10] and thus, when an indicator like litmus paper is placed in contact with a soil whose adsorptive powers are not already satisfied, the base in the indicator is adsorbed, leaving the free acid, which is red in the case of litmus. Treatment of the soil with a common salt like sodium chloride would result similarly, in that the sodium would be adsorbed and the chloride ion liberated. Where the hydrogen ion was to come from to make with

[9] A process of chemical analysis involving additions of standard solutions to substances until a certain definite effect, usually a change of color, is observed.

[10] See General Chemistry of the Soil, p. 911.

the acid radical (the anion) a complete acid was not always explained. If previous hydrolysis [11] of the salt or indicator was assumed with subsequent adsorption of the base and liberation of the acid, it left the anomalous situation that here in the case of soils a rather large amount and concentration of acid could intermingle with a like amount of adsorbed base without neutralization taking place. This, of course, is untenable. As a basis for these contentions, experiments with charcoal (impure) were cited. Subsequent experiments by Miller (*260*) with highly purified charcoal indicate that the acid formed on hydrolysis of a salt is adsorbed more than the base.

True Acids Cause Soil Acidity

Other investigators (*42*, *118*, *411*) clung to the premise that actual acids are involved in soil acidity. They believed that in acid mineral soils there are present not only the so-called humic acids but also insoluble mineral acids derived from the weathering of various silicates, the bases being removed by leaching. This viewpoint has proved to be essentially correct, and there is now no longer any question but that actual acids, mineral as well as organic, give rise to the condition recognized as soil acidity.

The more exact nature of the mineral acids involved has been elucidated largely through studies (*197*) of the phenomenon of base exchange, which is discussed elsewhere. Suffice it to say that base exchange signifies simply an exchange of bases or cations between two compounds containing different kinds of exchangeable cations. One of these, the base exchange compound, is not in true solution but is bathed by the solution of the other. If the one not in solution happens to have an unusually open or spongelike (zeolitic) structure, the phenomenon of exchange of bases or cations is of course greatly facilitated, because there is opportunity for the compound in solution to infiltrate into this open structure and thus allow for a complete exchange of cations in accordance with the law of mass action, much as though both of the pair were in true solution. If the particles of the one not in solution have a dense structure so that the solution cannot infiltrate into the interior but can bathe only the outside surface, then the extent of the exchange is greatly restricted and for many purposes is negligible.

Most of the mineral particles present in soils—quartz and feldspar, for example—have a dense structure, but it happens that there is at least one common soil mineral, an aluminum silicate, that has a very open structure and exhibits the phenomenon of base exchange in a perfect manner.[12] A suspension of the hydrogen-saturated compound in water gives a distinctly acid reaction (about pH 3) while a similar suspension of the base-saturated compound is neutral or alkaline. Its reaction range (approximately pH 3 to 8) when variously saturated is of sufficient extent to account for the reaction range of common soils.

Besides the mineral or inorganic exchange material, there also exists in soils organic exchange material whose chemical deportment is

[11] A chemical process of decomposition by water.

[12] When saturated with hydrogen in place of a base, this mineral has the empirical formula $Al_2O_3.4SiO_2.XH_2O$, and is in fact a true alumino-silicic acid. Ferric iron may replace the aluminum, and there is evidence that other replacements may take place to some extent (*244*), but for the purposes here the formula given suffices. The exact basicity of the acid (number of replaceable hydrogen atoms) is at present not definitely known.

quite similar to that of the inorganic material. When saturated with hydrogen, this organic exchange material constitutes the so-called humic acids, which seem to be derived largely from lignin (*228*, *266*).

The organic and inorganic exchange materials exist in soils as fine colloidal particles, sticking for the most part to the surface of the larger particles. When this exchange material is saturated with calcium (as is the case in a well-limed soil), it coagulates and causes a granulation of the whole soil mass—which accounts for the general physical improvement of clay soils when lime is applied. When saturated largely with hydrogen (as is the case in acid soils) or with sodium (as in alkali soils), the exchange material disperses or deflocculates, granulation of the soil is impaired, and poor physical condition results.

When the exchange material is largely saturated with hydrogen, the soil water or solution also tends to become acid, because it bathes the exchange material and is in equilibrium with it. Thus in the soil sulphuric, nitric, and carbonic acids are constantly being formed through biological activity. These on liberation immediately seek a base, and if the base exchange material is well saturated, they obtain it, become neutralized, and the soil solution remains neutral or nearly so. If the base exchange material is low in base saturation—that is, if it is distinctly acid—then these acids do not become completely neutralized, and being soluble, they cause the soil solution itself to become acid in direct proportion to the acidity of the exchange material. When lime is added, it serves to resaturate or reload the base exchange material with bases. The calcium in the form of the carbonate may, of course, directly neutralize the soluble acids of the soil solution without previous entrance into the exchange material.

Exchange Soil Acids Serve as a Storehouse

These exchange acids (humic and alumino-silicic) are not to be looked upon as detrimental or toxic substances. They form, in fact, the backbone of a good soil. Physically, they make possible a granulation of soils; and chemically they serve as a storehouse or repository for bases—calcium, magnesium, potassium, manganese, copper, and others—that may be easily drawn upon in exchange for hydrogen as needed by plants and the soil solution, much like money in a checking account. An acid condition of a soil is simply a warning that the supply of bases in the exchange material (the exchange bank) is getting low and needs replenishing. Way (*452*) in 1850 called attention to the presence and important function of these exchange materials in soils, but it was not until the past 10 years that the nature of the exchange compounds and their relation to soil acidity was at all well understood or fully appreciated.

FORMATION OF ACID SOILS

The inorganic exchange material is formed in the weathering of silicate minerals, possibly the feldspars or micas. If the bases, especially calcium and sodium, are largely removed by leaching during the weathering process, the exchange material on formation becomes saturated with hydrogen rather than bases, and the resulting soil is acid. If on the other hand the calcium and sodium are not removed by leaching and remain to saturate the exchange material as it is formed, the

resulting soil is then not acid, but may even be alkaline, especially if sodium and calcium carbonates are left over after saturation of the exchange material. From this discussion, it is apparent that extent of leaching is the main factor involved in determining whether or not the soil formed will be acid. Extent of leaching is determined largely by rainfall, age of soil, temperature, and vegetation. Of these, rainfall is in general the most important, and regions having an annual rainfall of 25 inches or more usually have a high percentage of acid soils. Such regions make up the eastern half of the United States, east of a line running from north to south through the middle of Minnesota, then slightly west, and down through the middle of Nebraska, Kansas, Oklahoma, and Texas. Certain areas on the west coast having considerable rainfall, particularly Oregon and Washington, are also acid.

Mucks and peats when formed in basins receiving drainage waters charged with alkali and alkaline earth carbonates are of course nonacid, since the organic exchange material formed from plant residues under these conditions becomes saturated with bases as fast as it is formed. Under other conditions, when the rate of inflow of basic compounds is insufficient to keep pace with the formation of organic exchange material, this material is left in an acid condition, as is the deposit or soil thus formed.

Organic exchange material is of course also formed in upland soils. Where the native vegetation is prairie grass, the amount thus formed, largely from the roots, may exceed that of the inorganic exchange material. Where the native vegetation is trees, the amount formed is usually much less and is confined largely to the surface layer. Under cultural conditions, the return of animal manure and plant residues contributes something to the formation of organic exchange material. This is beneficial, especially to sandy soils that lack a sufficiency of exchange materials.

The use of certain fertilizers has long been known to increase soil acidity. In this connection, ammonium sulphate has received considerable attention. When it nitrifies, two acid products result—nitric and sulphuric acids. These are both soluble and thus make the soil solution more acid, also increasing its tendency to remove bases from the exchange material so as to form a soluble salt. The soluble salt may be absorbed by plants or removed in the drainage water. In either case, the exchange material has lost some base and the soil as a whole is just that much more acid. Ammonium nitrate acts similarly, while calcium cyanamide and sodium nitrate have the opposite effect. Pierre (*301*), of the West Virginia Agricultural Experiment Station, has investigated the acid and base balance that results from the application of various fertilizer materials and fertilizer mixtures to soils, and has proposed a method for its determination in a sample of the fertilizer. Largely as a result of this work, much attention is now being given to compounding fertilizers that will have the most favorable reaction effect for any particular soil or condition.

Removal of bases at a greater rate than the acids through cropping also tends to leave the soil more acid by depleting the exchange acids of their bases. The legumes, particularly alfalfa and clover. make a heavy drain in this respect.

THERE has always been erosion; it is when man steps in and destroys the balance of nature that it becomes highly destructive. This article considers the erosion problem from a broad standpoint. The authors tell just how water and wind erode unprotected soil and describe the extent and distribution of the damage it has done in this country, including the results in loss of topsoil and soil nutrients. They deal briefly with the economic aspects of erosion and summarize the principal steps that may be taken to control it, ending with their conception of the requirements of a national soil conservation program.

General Aspects of the Soil-Erosion Problem

By Hugh H. Bennett *and* W. C. Lowdermilk [1]

SOIL EROSION is as old as agriculture. It began when the first heavy rain struck the first furrow turned by a crude implement of tillage in the hands of prehistoric man. It has been going on ever since, wherever man's culture of the earth has bared the soil to rain and wind.

It is not to be confused with geologic erosion, which, as part of the complex process of rock weathering, is essential to the formation of soil and aids in its distribution from place to place. Geologic erosion takes place in a natural, undisturbed environment, where vegetation, with its canopy, stems, ground cover of litter, and underground network of binding roots, retards the transposition of surface soil by wind, rain, and gravitational movement to a pace no more rapid, generally, than that at which new soil is formed from the parent materials beneath. It is a gradual, normal process, probably beneficial as a rule, seldom harmful in effect.

Soil erosion, on the other hand, is a vastly accelerated process brought about by human interference with the normal equilibrium between soil building and soil removal. Where the land surface is bared of protective vegetation—as it must be under cultivation—soil is exposed directly to the abrasive action of the elements (fig. 1). Transposition processes of an extremely rapid order are set in motion, and soil is bodily displaced much faster than it can be formed. Unless adequate measures are taken to guard against this abnormal, highly accelerated phenomenon of soil removal, it becomes the most potent single factor contributing to the deterioration of productive land.

Through the ages, soil erosion has exerted a tremendous influence on the course of civilization. History is largely a record of human

[1] Hugh H. Bennett is Chief and W. C. Lowdermilk Chief of the Division of Research, Soil Conservation Service.

struggle to wrest the land from nature, because man relies for sustenance on the products of the soil. Yet too frequently man's conquest of the land has been disastrous; over extensive areas, his culture of the earth has resulted in extreme impoverishment or complete destruction of the soil resource on which he is dependent. So direct, in fact, is the relationship between soil erosion, the productivity of the land, and the prosperity of a people, that the history of mankind, to a considerable degree at least, may be interpreted in terms of the soil and what has happened to it as the result of human use.

Recent archeological studies suggest that the hand of man, rather than climatic change, caused once rich and populous regions to be

Figure 1.—Erosion of bean land in southern California by one rain. There was no erosion in the natural vegetated area above the cultivated field.

reduced to poverty or complete abandonment. Abuse or neglect of the land that sustained their populace and their commerce is believed to have played a major part in the decline of civilizations now extinct.

J. A. Ainslie of Nigeria, South Africa, has the following to say about the French Niger Colony (*2*):[2]

A few months ago I had the opportunity of visiting the French Niger Colony lying to the North of the Nigerian boundary; that country is very largely desert and includes within its area probably the most dreaded desert region in the world; nevertheless, throughout the country there are many ruins of ancient towns and villages; it was evidently at one time heavily populated, and so must have been a well-watered region. There are both Arab and French records to show that up to the middle and towards the end of the 18th century . . . these towns were inhabited by an active farming and trading people; the area, however, became deforested and it has only taken some 200 years to depopulate a country as large

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

as the Union of South Africa . . . First came the shifting cultivator with his axe and fire; secondly, the grazier with his camels, cattle, sheep and goats . . . and now comes the desert . . .

Some archaeologists and geographers believe that portions of the Sahara, the central Asian deserts, and parts of Palestine, Mesopotamia, and the Gobi once teemed with human life (*173*, *223*, *384*). It is said that 500 cities once flouished in what are now the dry, depopulated plains of Asia Minor (*243*). Tepe Gawra, whose ruins were recently discovered in northern Mesopotamia, is thought to be the oldest town in the world of which remains still exist. This was a well-planned city as early as 3700 B. C. and must have represented long ages of prior development (*106*). The capital of the rich kingdom of the Queen of Sheba is believed to have been found under shifting sands (*45*). Parts of the west coast of South America, where the oldest known civilizations in the Western Hemisphere existed, are treeless and barren.

In the decline of these civilizations many factors other than erosion played a part. War and pestilence, for example, were common in the ancient world. But civilizations are rooted in the soil. Cities are fed on the produce of the land; much of their commerce depends upon it. The very fact that regions scarcely habitable today once supported rich cultures is evidence in itself of the decline of the land. Climatic changes, to which this fact is frequently attributed, have occurred in the geologic past and are doubtless still in progress; but they usually take place far too slowly to affect human institutions or history in any immediate sense. The progressive deterioration of the land resulting from abuse or neglect seems certainly to have contributed to the crumbling of ancient civilizations. Whether this neglect was caused by economic or political conditions is a matter for historians to decide.

EROSION BY WATER

Water and wind are the active forces of soil erosion, differing in the nature of their action and in outward manifestation, but similar in the sense that both remove and transport surface soil. Both represent major problems having to do with land defense and preservation.

Water erosion is the transposition of soil by rain water (including melting snow) running rapidly over exposed land surfaces. It is conditioned by factors of slope, soil type, land use, and intensity of rainfall, and is confined to sloping areas, where the land is of a kind susceptible to washing and where land-use practice has stripped the surface of protective vegetation. It is a progressive process, aggravated by cultivation and overgrazing and sometimes by burning. In general, it may be divided into three types, which, while closely related, are by no means mutually exclusive. Two or more of them may occur simultaneously in the same field; one may develop into another. But for the purposes of discussion, the general category of water erosion may conveniently be subdivided into sheet erosion, rill erosion, and gully erosion.

Sheet erosion is the more or less even removal of soil in thin layers over an entire segment of sloping land. It is the least conspicuous and the most insidious type of erosion. Frequently it causes the

color of the land to change gradually from dark to light as the removal of dark-hued, humus-charged topsoil exposes light-colored, humus-deficient subsoil (fig. 2). Often this change in color is accompanied by a progressive decline in yield (fig. 3).

Unprotected land varies widely in its susceptibility to sheet erosion, the differences depending on topographic features, climatic environment, and the character of the soil. Steep and fairly steep lands and those subjected to heavy or intense rainfall are most likely to be problem areas. But the vulnerability of any field or pasture to sheet erosion is conditioned in an important degree by the inherent erodibility of the soil itself. Areas where a loose, shallow layer of surface

Figure 2.—Light-colored subsoil exposed by sheet erosion of moderately sloping land near Mankato, Kans.

soil overlies a dense subsoil of low permeability are peculiarly susceptible to this form of water erosion. It is also likely to prevail on soils of high silt content, fragile sandy soils, stiff clays, and all soils deficient in organic matter. Actually, sheet erosion takes place to some extent wherever water flows across unprotected sloping land.

Instead of flowing evenly over a sloping field, run-off water generally tends to concentrate in streamlets of sufficient volume and velocity to generate cutting power. The result of this form of run-off is rill erosion, which, in contrast to sheet washing, is characterized by small incisions left in the land surface by the cutting action of the water. Rill erosion is more apparent than sheet washing, but almost as often neglected. The small incisions are easily obliterated by the

ordinary operations of tillage. Farmers are likely to forget the tiny gashes or to minimize their importance once they are smoothed out with agricultural implements (fig. 4).

Run-off water ordinarily concentrates in rill-producing streamlets only where there is an intense rainfall and a relatively small amount of percolation. Rill erosion is consequently most common in regions of rather intense precipitation and on lands of low absorptive capacity. Soils with a high silt content are especially vulnerable, although the process usually occurs during heavy rains on all areas where loose soils overlie dense subsoils. The sudden melting of snow, such as occurs in the Palouse (southeastern Washington and adjacent parts

Figure 3.—This Alabama field, which originally produced more than one-half bale of cotton per acre, has suffered so severely from sheet washing that more than 400 acres would have been required to produce a bale in 1936, when this picture was made. All of the topsoil has been washed off, along with part of the subsoil. White dots represent the total cotton crop.

of Idaho and Oregon) under the impact of warm winds from the west (chinooks), produces very severe rill erosion.

Gully erosion takes place either where the concentrated run-off from a bare slope increases sufficiently in volume and velocity to cut deep incisions (gullies) in the land surface, or where the concentrated water continues cutting the same groove long enough to develop such incisions. Usually gullies follow sheet erosion or result from the neglect of rills. But frequently they have their beginning in slight depressions of the land surface, where run-off water normally concentrates. Often they develop in natural field depressions or in ruts left by the wheels of wagons driven up and down hill over soft ground. They frequently form also in livestock trails and along furrows running up and down the slope.

FIGURE 4.—Rill erosion in an Oregon prune orchard as a result of spring rains, 1937. The farmer smooths over these little incisions with his plow and forgets them until the next rain.

Once the gullying process has started, the shape of the incision is generally influenced by the relative stiffness, or resistance, of the soil strata and of the underlying rock material. For example, over much of the loessial regions and alluvial valley fills of the West, both surface soil and subsoil are commonly friable and easily cut by flowing water. Under such conditions, gullies tend to develop vertical walls which result from undermining and collapse of the banks. The barrancas that have cut so deeply into portions of the landscape of California and various parts of the Southwest are a typical example of this U-shaped type of gully.

Where the subsoil is resistant to rapid cutting because of its heavy

Figure 5.—Every year advancing erosion destroys valuable cropland. This gully, more than 100 feet deep, and others like it, have ruined 100,000 acres of land in one Coastal Plain county in the Cotton Belt.

texture or toughness, and especially where the underlying geological material, or substratum, is not essentially softer than the subsoil, gullies develop sloping banks and take a V-shaped form. This type is commonly found in humid areas where the surface soil is underlain by a stiff clay. Although V-shaped gullies usually develop less rapidly than other types, they frequently present an equally serious hazard.

Still another type, representing a combination of the U-shaped and V-shaped gullies, prevails in certain localities. This third type develops first as a V-shaped gully. But after the water has cut below the resistant subsoil, it strikes an underlying stratum of loose or soft rock material. Undercutting and caving then occur and the incision changes from a V-shaped to a U-shaped channel. In the more advanced stages these gullies closely resemble the barrancas of the

West. Through the southern Piedmont region, especially in localities where decomposed granite underlies a subsoil of brittle clay, and in rolling sections of the southeastern Coastal Plain, where moderately firm sandy clay overlies a very soft sandy stratum, gullies of this third type have developed within half a century to a depth of 50 to 100 feet or more (fig. 5).

Aside from ruining land by gashing it to pieces, gullies gather run-off water and discharge it at maximum speed, damaging lower lands and intensifying the danger of floods and washouts. They also pour out relatively unproductive subsoil material to cover lower slopes and alluvial plains.

In this connection, it should be noted that the finer products of erosion—the lighter particles of soil—are carried greater distances

FIGURE 6.—Sand deposit left on valuable cropland by the Ohio River flood in January 1937. This field in 1936 produced 100 bushels of corn per acre and was valued at $100 per acre.

than the coarser, heavier particles. As a result, the less productive coarser material—sand gravel and sometimes cobbles—frequently is left behind to damage valley lands (fig. 6).

An example will illustrate how violently rushing flood water assorts the finer, more productive material from soil washed into streams, to leave behind coarser and much less productive alluvium.

In the latter part of September 1936, as a result of the destructive flood produced by a 9½-inch rain, a layer of coarse sand, ranging up to 24 inches in depth, was deposited over the much finer textured soil of portions of the alluvial plain of Eighteen-Mile Creek, near Clemson College, S. C. Analysis of this coarse, light-colored material (table 1) shows a content of only 0.10 percent of organic matter,

0.01 percent of phosphorus, and 0.007 percent of nitrogen. As compared with this almost sterile sand, the original dark-colored, fine-textured, productive virgin soil 90 inches beneath the surface shows a content of approximately 30 times as much organic matter, 13 times as much nitrogen, and 16 times as much phosphoric acid.

Table 1.—*Chemical and physical analyses*[1] *of surface, intermediate,*[2] *and deep alluvial deposits (original flood-plain deposits), through the profile of the alluvial plain of Eighteen-Mile Creek, near Clemson College, S. C. (about 200 yards below Anderson-Clemson College Highway, south side of creek)*

Composition	Light-colored surface layer deposited by flood of Sept. 29, 1936, 0–24 inches deep	Layer immediately beneath surface deposit, 25–32 inches deep	Dark-colored layer[3] 90–93 inches deep
	Percent	*Percent*	*Percent*
Organic matter	0.10	1.47	2.98
Nitrogen	.007	.04	.09
Phosphoric acid	.01		.16
Potash	2.41		2.44
Fine gravel	4.5	.2	.0
Sand (coarse, medium, fine, and very fine)	93.4	83.5	17.1
Silt and clay (diameter, silt—0.05–0.005 mm, clay—0.005–0 mm)	2.0	15.3	80.1
Ultra fine (colloid diameter 0.002–0 mm)	1.0	7.6	32.5

[1] Analyses by Bureau of Chemistry and Soils; samples collected by Soil Conservation Service following record flood of Sept. 29, 1936.
[2] The layers between the depths of 33 and 90 inches were highly diverse texturally, but averaged finer grained than the layers above and coarser than those below.
[3] Probably representing virgin soil at beginning of agricultural operations in watershed.

EROSION BY WIND

In its arena of activity, erosion by wind presents a problem of equal gravity to that of water erosion. Often it occurs in areas where water erosion is also active, but in any one locality the two types rarely assume an equal degree of importance. Soil washing attains its most serious proportions on land with a considerable degree of slope and an intensive rainfall; soil blowing becomes an acute problem on both level and sloping areas of low rainfall.

Unlike erosion by water, wind erosion is not easily divisible into forms or subtypes. One example of soil blowing ordinarily differs from another in degree rather than in kind. In severity, however, wind erosion may range all the way from a slight disturbance of the surface soil over a small area to the huge dust storms that sweep across many States, remove countless tons of soil, and constitute a major catastrophe.

Under conditions of normal ground cover and natural soil equilibrium, wind erosion proceeds at a slow, geologic rate. Air currents pick up soil material in small quantities, transport it from one area to another, and aid in the development of new soils. But in relatively flat and gentle undulating treeless regions, like the Great Plains, where the sweep of winds is almost unbroken by topographic irregularities, drastic disturbances of the natural vegetative cover bring on a tremendous acceleration of the wind-erosion process.

When the grass cover is removed by plowing, the original stability of the soil is greatly reduced. Cultivated soil, depleted of the binding effect of grass roots and of the spongy organic matter which normally accumulates under a cover of grass, becomes less cohesive. After periods of subnormal rainfall, it turns into a dry, powdery substance, lying loosely over the surface of the land. This loose, dry material is easily swept up by the wind and transported over long distances. The coarser, heavier particles left behind are blown along near the surface to accumulate around obstacles in their path, such as clumps of vegetation, ground hummocks, houses, farm implements, fences, etc.

Soils vary considerably in their resistance to wind erosion, depending generally on their structure, the size of their particles or texture, and their content of organic matter. Neither coarse sands nor heavy clays are immune. In fact, the former are extremely susceptible and usually begin to blow immediately after plowing. The finer-textured soils, especially those of granular structure, generally show the greatest resistance. These sometimes remain undisturbed through years of cultivation, although when subjected continuously to diminution of organic matter under cultivation, the granules break down eventually and the deflocculated particles are susceptible to wholesale removal by wind action.

The action of wind, as well as water, upon the soil is something like that of a sieve. Wind picks up the lighter, more fertile soil particles and lifts them into the pathways of high air currents, which often carry them for hundreds and sometimes thousands of miles. The coarser, less fertile particles skip and roll along the surface until they pile up in drifts behind obstacles. A comparison of the soil material blown away by a dust storm with that left behind reveals in striking fashion this sifting nature of the wind-erosion process.

Table 2.—***Chemical and physical analyses of virgin soil, dune sand, and dust derived from cultivated soil as the result of a dust storm on and preceding February 6, 1937*** [1]

Composition	Grassland near Dalhart, Tex. (virgin soil profile)	Sand dune near Dalhart, Tex. (formed on and immediately preceding Feb. 6, 1937)	Dust, near Clarinda, Iowa (collected from surface of snow, Feb. 8, 1937)
	Percent	*Percent*	*Percent*
Organic matter	1.06	0.33	3.35
Nitrogen	.06	.02	.19
Phosphoric acid	0.4	(2)	.19
Potash	2.05	1.77	2.58
Sand (coarse, medium, fine, and very fine)	79.2	91.8	.0
Silt and clay (diameter, silt—0.05—0.005 mm, clay-0.005-0 mm)	19.6	7.5	97.0
Ultra fine (colloid diameter 0.002-0 mm)	8.1	5.2	33.4

[1] Samples of grassland and new dune collected by H. H. Finnell, Soil Conservation Service; dust sample collected by R. A. Norton, Soil and Water Conservation Experiment Station, near Clarinda, Iowa; analyses by Bureau of Chemistry and Soils

[2] Trace.

Early in 1937 a dust storm originating in the Texas-Oklahoma Panhandle country traveled northeasterly across five States and on into Canada. Soil material laid down by the storm on snow and ice in

Iowa was collected and compared with samples taken from a small dune formed by the same wind disturbance near Dalhart, Tex. Analysis showed that the dust carried a distance of more than 500 miles contained 10 times as much organic matter, 9 times as much nitrogen, and 19 times as much phosphoric acid as the dune sand piled up in the general locality of the storm's source (table 2). The transported material was also of much finer texture, containing no sand as against more than 90 percent sand in the residuary, drifting dune left behind.

SOIL EROSION IN THE UNITED STATES

In the United States, physical, economic, and social circumstances have contributed to the spread of soil erosion at a rate perhaps unequaled in history. Physically, more than three-fourths of continental United States is subject, in some degree, to some form of erosion process, when the land is exposed to the effects of wind and rain. Conditions of climate, ranging from extremes of intense and frequent rainfall in one region to intense and frequent drought in another, are peculiarly conducive to both wind and water erosion. Fully 75 percent of the land surface of the country slopes sufficiently to discharge rain water at an erosive rate,[3] yet, in the Great Plains, the land surface is sufficiently flat and open to permit also the unobstructed sweep of wind across that subhumid or semiarid area. Soils differ widely, but only a few of the numerous varieties are immune from erosion in some form or some degree.

Moving over these naturally vulnerable lands, the march of agricultural occupation across the United States left widespread soil erosion in its wake. The pioneering ax and plow rapidly upset the interplay of natural forces that had formed and preserved rich soils through ages of undisturbed development. The same tide that rolled the frontier forward from the Atlantic rolled back nature's stabilizing mantle of trees and grasses and bared virgin soil to wind and rain.

If there seems to have been a remarkable disregard of the natural consequence, the reasons, in retrospect, are easily understood. The period of development in any country is likely to be a period of exploitation; perhaps exploitation, in a sense, is essential to development. The early colonist in this new world entertained an illusion of everlasting land abundance. As long as man could "wear out" one farm and move to another lying westward, he had little concern for the land. He had none of the sense of utter dependence upon the soil that makes husbandmen of farmers in countries where land is scarce.

Many of those who pushed the frontier westward were farmers by heritage. But most of them were accustomed to an agriculture under physical conditions quite different from those existing here. Englishmen, for example, knew the grass agriculture of England with its misty gentle rains. The effect of torrential rains on cultivated, unprotected soil, was a phenomenon with which many of them had had little or no experience.

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[3] On the basis of all available topographic data, the U. S. Coast and Geodetic Survey estimates that about 90 percent of the land in the United States has a slope of 2 percent or more. Every known measurement at erosion experiment stations throughout the country shows some loss of both soil and water on unprotected slopes of 2 percent and more.

Extent and Distribution

The extent of land damage caused by soil erosion during America's brief period of exploitative land use, ranging for the most part from about 50 to 100 years, has not been accurately appraised. Thus far, only reconnaissance surveys have been made over the greater part of the affected areas; more detailed investigations are now under way. Reconnaissance data indicate, however, that of the total land area of the United States, excluding mountains, mesas, and badlands, approximately 282 million acres have been either ruined or severely damaged by soil erosion. An additional 775 million acres have lost from one-fourth to three-fourths of their topsoil.

FIGURE 7.—Destruction of productive Kansas land as the result of cultivating up and down slope.

The 1935 Census of Agriculture shows that at the present time there are slightly more than 414 million acres of cropland in the United States. This acreage, plus an indeterminate area formerly cultivated and subsequently retired to trees and pasture or allowed to stand idle, constitutes the past and present cultivated land of the country. Of this aggregate area, about 50 million acres has been essentially ruined for cultivation and an additional 50 million acres has been almost as severely damaged by soil erosion (fig. 7). Another 100 million acres, largely still in cultivation, has suffered such severe removal of fertile topsoil and consequent loss of fertility that most of it is only one-tenth to one-half as productive as it was. In addition, erosion is rapidly becoming a menace to land values and continuing productivity on another 100 million acres.

Furthermore, in the light of data collected for the present cropland

area only, an appraisal indicates that under current farming practices and with price conditions similar to those prevailing since 1921, about 43 percent of this area is in need of good soil-conservation and farm-management practices if further damage from erosion is to be prevented.[4] The scope of erosion control on farms, however, is not limited to cropland alone, but also includes pasture and range areas and some improperly managed woodlands and forests.

Following is a summary of approximate erosion conditions in the United States today, the figures being estimates based primarily on the results of reconnaissance surveys.

	Acres
Total land area (exclusive of large urban territory)	1, 903, 000, 000
Erosion conditions not defined (such as deserts, scablands, and large western mountain areas)	144, 000, 000
Total land area (exclusive of mountains, mesas, and badlands):	
Ruined or severely damaged	282, 000, 000
Moderately damaged	775, 000, 000
Cropland (cropland harvested, crop failure, and cropland idle or fallow):	
Ruined for cultivation	50, 000, 000
Severely damaged	50, 000, 000
One-half to all topsoil gone	100, 000, 000
Erosion process beginning	100, 000, 000

These damaged lands are widely scattered over the surface of continental United States. Erosion has extended into practically every major agricultural region and has affected, in some degree, the production of nearly every staple commodity. Only level areas such as occur in parts of the Coastal Plain, the smoother portions of the Mississippi Valley, and in swamps and marshes are entirely free of its ravages. The problem of water erosion is most acute on a wide scale, however, in the rolling parts of the Cotton, Corn, and Tobacco Belts, while wind erosion is most widespread in the Great Plains and in somewhat similar areas farther west. The erosion map (p. 93) shows in a very general way the distribution of the more serious forms of erosion in the United States, with degrees of severity indicated by the shading.

RATES OF SOIL EROSION

The rates at which soil is removed by wind and water from agricultural land vary greatly with different conditions of slope, soil, climate, and land use. When the first three factors are approximately identical, as they are on the adjoining plots where the measurements were made, the effect of land use on water erosion rates is found to be far-reaching and profound (table 3).

Quantitative measurements of surface run-off and of solids transported by the run-off, under both natural and disturbed ground conditions, disclose the fact that the process of surface removal is vastly more rapid when the ground lacks vegetative cover than when such a cover exists.

Table 3 shows the actual amount of erosion and the percentage of total precipitation lost as run-off from five widely separated, extensive, and important types of farm land. The comparison here is

[4] See the article, The Problem: The Nation as a Whole, p. 94.

between two types of crops, one clean-tilled, such as corn, cotton, and tobacco (erosion-inducive crops), and the other thick-growing, such as grass, alfalfa, and lespedeza (erosion-resistant crops). The results show that, on the average, a covering of dense vegetation on these lands is 313 times more effective in retaining soil and 6 times more effective in retaining rainfall than clean-tilled crops on the same kind of land.

Table 3.—*Annual soil and water losses per acre from five widely separated types of land under conditions of clean tillage and dense cover of vegetation* [1]

Soil, location, and years of measurements	Average annual precipitation	Slope	Clean-tilled crop		Dense cover—thick-growing crop		Approximate years to remove 7 inches of soil [2]	
			Annual soil loss	Annual water loss	Annual soil loss	Annual water loss	Clean tillage	Dense cover
	Inches	*Percent*	*Tons*	*Percent* [3]	*Tons*	*Percent* [3]	*Number*	*Number*
Shelby silt loam, Bethany, Mo., 1931-35	34.79	8.0	68.78	28.31	0.29	9.30	16	3,900
Kirvin fine sandy loam, Tyler, Tex., 1931-36	40.82	8.75	27.95	20.92	.124	1.15	49	11,100
Vernon fine sandy loam, Guthrie, Okla., 1930-35	33.01	7.7	24.29	14.22	.032	1.23	50	38,200
Marshall silt loam, Clarinda, Iowa, 1933-35	26.82	9.0	18.82	8.64	.06	.97	48	15,200
Cecil clay loam, Statesville, N. C., 1931-35	45.22	10.0	22.58	10.21	.012	.33	51	95,800

[1] Measurements at the soil and water conservation experiment stations of the Soil Conservation Service.
[2] Based upon actual volume-weight determinations of the several soils as follows: Shelby silt loam 1.13, Kirvin fine sandy loam 1.73, Vernon fine sandy loam 1.54, Marshall silt loam 1.15, Cecil clay loam 1.45—apparent specific gravities.
[3] Of total precipitation.

The time required for erosion to strip 7 inches of the more productive topsoil from these five important types of land (7 inches being about the average depth of the topsoil of these types), as estimated on the basis of their respective rates of erosion, ranges from about 3,900 to 95,800 years under a dense cover as against 16 to 51 years where the land is subjected continuously to clean tillage.

Measurements of erosion in a number of other major agricultural regions of the country have produced similar results. The rate of water erosion on any one plot depends partially on slope, soil, and amount and intensity of rainfall; but the comparative rates on adjoining plots of identical soil and slope, subjected to the same amount and intensity of rain, show a marked relationship to land use or type of cover. Erosion damage is consistently heavier on land planted to a clean-tilled crop year after year than on plots under a good rotation; and soil losses, as well as water losses, from fallow land bare of vegetation are uniformly much greater than from land in grass or trees.

Although experimental data are not available on the rates of wind erosion, experience indicates a similar definite relationship between the rate of soil removal, plant cover, and land use. Dense vegetation shields the soil from wind and binds it down with roots, just as it protects the soil from removal by water.

Unless checked by mechanical or vegetative controls, erosion normally proceeds at an increasing rate as the upper layers of soil are successively removed. The more absorptive humus-charged topsoil is generally more resistant to erosion than the less absorptive, less stable layers beneath. It is permeated with millions of structural air spaces and with openings caused by decaying plant roots or burrowing earthworms, insects, and animals. Spongelike organic matter keeps it granular, absorptive, and cohesive. Heavy rains tend to seal over the soil pores of bared fields and the larger openings into the body of the soil are choked with muddy injections. Eventually, underlying layers deficient in organic matter are exposed. Such exposed material, whether of clay or of coarser grain, is more erodible as a rule. With very few exceptions, the exposed subsoil (B or C horizon) is distinctly more erodible than the layers of the topsoil (A horizon). Run-off water concentrates in greater volume and moves with mounting speed and erosive effect as gullies are cut deeper into the body of the earth.

EFFECTS OF EROSION

The accelerated erosion of soil taking place with unwise cultural practices has had increasingly deleterious effects on the physical body of the land. Within the past century, it has made cultivation economically unsound on more than 20 percent of the tilled land (present and past) of the country, for a long time to come at any rate; it has narrowed the potentialities of agriculture and limited the area in which it may be practiced successfully.

Together, water and wind erosion remove not less than 3 billion tons of soil from the croplands and associated pastures of the Nation every year.[5] Some 730,000,000 tons of solid matter are carried annually into the Gulf of Mexico by the Mississippi River alone.[6] Much material washed out of fields and pastures is deposited en route to the sea.

This 3 billion tons of wasted soil contains the equivalent of some 90 million tons of phosphorus, potassium, nitrogen, calcium, and magnesium. Of this, 43 million tons represents phosphorus, potassium, and nitrogen, the principal ingredients of commercial fertilizer. This is more than 60 times the amount of these elements of plant food used in the United States as commercial fertilizers during the fiscal year ended June 30, 1934.[7]

[5] Soil losses from land under wheat, corn, and cotton as measured on experimental plots at the soil erosion experiment stations over periods ranging from 1 to 7 years average 24.66 tons per acre per year (46.26 tons per acre under corn, 5.76 tons per acre under wheat in rotation, and 21.98 tons per acre under cotton). These measurements involve a wide range of soil type and slope. The annual acreage of corn, wheat, and cotton for the 10-year period 1926–35 averaged 193,491,000 acres. Assuming that three-fourths of this annual acreage was subject to erosion, the total annual soil loss approximated 3,555,397,125 tons per year. This estimate takes no cognizance of losses from large acreages in beans, potatoes, tobacco, and other tilled crops that provide little or no protection against erosion.

[6] Littlefield (1923) estimated the annual silt discharge of the Mississippi River at 400 million tons. Steinmyer (1930) estimated the material carried in suspension at New Orleans at 510 million tons per year. The latest estimate, 1936, made by R. J. Russell (*221*), professor of physical geography, University of Louisiana, places silt discharge at the mouth of the Mississippi at 2 million tons per day, or 730 million tons per year.

[7] The average composition of surface soil in the United States as computed from chemical analyses of 389 samples of important soils, indicates a content of 1.59 percent of potash, 0.15 percent of phosphoric acid, 0.10 percent of nitrogen, 1.56 percent of lime, and 0.84 percent of magnesium (*31*). In the 3 billion tons of soil estimated to be removed from cultivated and pastured lands by erosion annually, these percentages equal, respectively, 1,966,212 tons of phosphorus, 38,601,900 tons of potassium, 15,199,860 tons of magnesium, 33,445,140 tons of calcium, and 3,000,000 tons of nitrogen. The total amount of phosphorus, potassium, and nitrogen lost annually in this 3 billion tons of soil is, therefore, 43,568,112 tons. Commercial fertilizer used in continental United States during the fiscal year 1934 contained 656,000 tons of phosphorus, potassium, and nitrogen according to figures of the National Fertilizer Association (*251*).

No other process or combination of processes is so destructive of valuable soil and its nutritive constituents as erosion. By comparison, the removal of plant-food constituents by cropping and grazing is relatively small.

More important than the loss of plant-food constituents through erosion, however, is the loss of soil itself. Erosion removes the entire physical mass of the soil—the mineral particles, the plant nutrients, the beneficial microscopic organisms, and all other constituents; in other words, the whole body of the soil itself. Crops, on the other

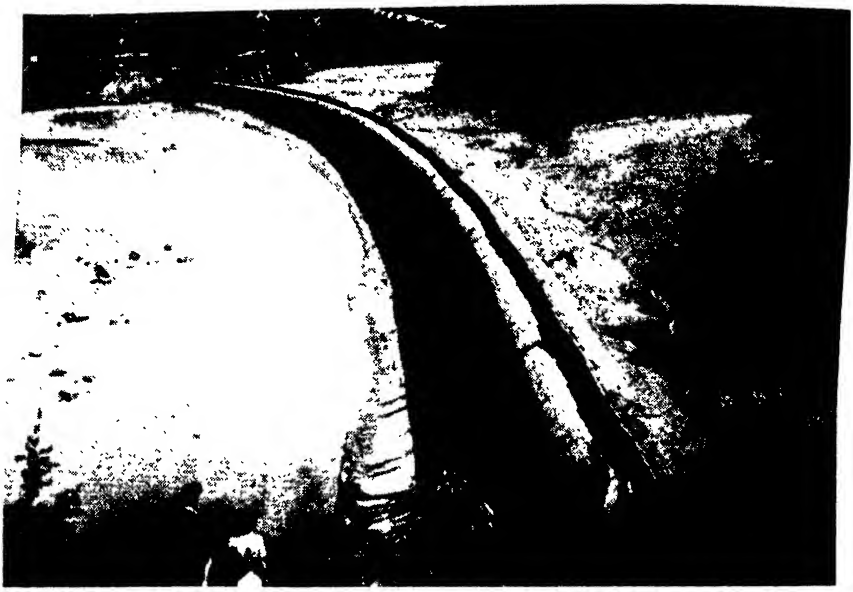

FIGURE 8.—Dam, reservoir, and powerhouse on Dan River, Schoolfield, Va. Capacity at completion in 1904, 4,000 acre-feet; by 1930 this was reduced by deposition of erosional debris to 780 acre-feet, amounting to a loss of 80 percent of the original capacity. Vegetation advancing on deposits in reservoir had nearly reached the dam at that time.

hand, remove only selected parts of the soil—the immediately soluble constituents upon which they feed. Thus, while crops impoverish the land, they extract only diminutive portions of the soil, leaving the bulk of the material, which may subsequently be improved with manures and soil-building crops. Erosion, if not checked, eventually takes all, leaving nothing to be improved.

Important also is the fact that the physical effects of erosion are not confined to land impoverished or ruined by the loss of soil. They extend, in the instance of water erosion, to adjacent lower areas and to alluvial plains far and near, as well as stream channels, drainage and irrigation ditches, reservoirs, and harbors, where a large portion of the material removed from eroding lands comes to rest (fig. 8). In some sections, rich land along lower slopes, needing no increment of soil, has been covered deeper and deeper with material washed down from upper slopes. Similarly, productive alluvial plains along

many streams have been covered, first by fertile soil lost from the fields and pastures of nearby or distant highlands, and then with relatively poor subsoil material discharged by gullies and washed from erosion-stripped slopes. Unproductive and troublesome sand and gravel assorted by waters from the mass of erosional debris also are deposited on valuable lowlands.

Frequently, such alluvial deposits clearly reveal the changes that have taken place in the soil profile since the beginning of agriculture within a drainage basin. Often the line separating the more uniform, finer grained alluvium laid down by shallow overflows of moderate turbulence during the period of virgin land conditions, and the less uniform, coarser grained deposits of the more violent floods that followed agricultural occupation, is so distinct that it can be photographed easily. An interesting example, referred to above, is found in the deposits laid down over the old alluvium of the preagricultural stage along Eighteen-Mile Creek, near Clemson College, S. C. The latest flood along this stream, on September 29, 1936, was reported to be the most violent and destructive of record; it deposited the coarsest layer of material found through the entire profile—clean, coarse sand, composed largely of quartz fragments, and essentially sterile for normal crop production (table 1).

The dislocation of soil caused by erosion has contributed to increased flood heights along many streams. Channels once comparatively deep and narrow have become shallow and broad with continued deposits of soil material washed down from eroding uplands. Their water-carrying capacity has been reduced almost proportionately with the amount of deposition. Yet superimposed upon this reduced channel capacity has come an increasing volume of run-off water with every hard rain. Thousands of fields, stripped of their protective cover of vegetation and eroded down to impervious clay subsoil, shed water almost as rapidly as it falls. Millions of new tributaries, in the form of gullies, concentrate this run-off water and empty it with maximum speed into already overfull streams. Thus, streams clogged with the debris of erosion now overflow adjacent bottomlands more frequently, often laying down deposits of unproductive soil material and developing swampy conditions that make formerly productive lands unfit for cultivation.

Wind erosion also has had damaging effects of enormous proportions. Spectacular dust storms have rolled across half the continent to dissipate themselves over the Atlantic Ocean or the Gulf of Mexico. Yet these storms probably do not represent the most damaging form of wind erosion. Low, sweeping winds that drive dust and sand before them without assuming the towering proportions of dust clouds have been more destructive in many localities because they have attacked the land with more regularity. They have blown silt and sand over thousands of acres of range and cropland, smothering plant life and killing off whatever chances there may have been for a harvest or a cover of grass. Often the abrasive force of these wind-driven soil particles has sliced off plants at their roots. In many instances, the shifting, blowing soil has covered highways and formed troublesome drifts and dunes that are a constant menace to adjoining farm lands. In all its forms, wind erosion has become a doubly destructive process

that now frequently plagues a vast area of the Nation from 3 to 6 months of the year—(1) by removing fertile soil from fields where it is needed, and (2) by depositing relatively infertile soil on lands where it is neither needed nor welcome. Surveys indicate that the productivity of about 10 million acres has been essentially depleted by wind erosion alone and that a much larger area has been damaged in varying degrees.

To the people living in regions subject to wind erosion, the process has become both an economic and a social menace. It is not only

Figure 9.—Oklahoma farm buildings partly covered with sand swept from wind-eroding fields during a dust storm.

impairing or destroying the basis of their major industries, agriculture and grazing; it is blanketing homes, offices, and mercantile establishments with dust, covering sheds and other small buildings with sand, and damaging agricultural machinery (fig. 9).

Because the soil-erosion problem has not long been recognized in all its ramifications, no accurate appraisal has been made of many of its effects. For example, there are no comprehensive data available at present to show the total damage of wind erosion or the number of stream channels clogged with the debris of water erosion. The exact extent of damage to roadway and railway embankments and cuts, the number of highways covered with silt, sand, or gravel, and the number of irrigation and drainage channels choked with mud are undetermined. No thoroughgoing survey has yet been made of the amount of property destroyed by silting and no complete record of the cost of river and harbor dredging operations necessitated by concentration of erosional debris has been compiled. Limited data are available on the sedimentation of water supply, irrigation,

and power reservoirs, but no Nation-wide figures. Yet, while precise statistical information is sorely needed, little more than casual observation is required to gage the trend and ascertain the enormous amount of damage to the physical soil resource of the country.

ECONOMIC IMPLICATIONS

From an economic and social standpoint, the implications of soil erosion are extensive and important. Without attempting here to explore this phase of the problem in detail,[8] it is pertinent to observe that soil conservation, in its larger aspect, involves a complex cause-and-effect relationship between the physical process of soil removal and many of the social and economic ills besetting agriculture.

It is almost axiomatic that any process which destroys the essential productivity of the soil can exercise only an adverse effect on an economy that depends fundamentally upon the soil. Erosion is such a process, perhaps the most vicious. Other factors being equal, its adverse effect on agricultural economy will be reflected usually in the progressive deterioration of productive land and in lower farm returns. In extreme cases it may lead eventually to submarginality, abandonment, rural migration, disruption of the tax base, general community disintegration, and similar maladjustments of an economic and social nature. This is not to say, of course, that soil erosion is either the sole or a primary cause of such maladjustments. But certainly it must be grouped with other factors of a physical, social, and economic nature which exercise a debilitating effect upon agriculture generally.

Temporarily its ill effects may be totally or partially offset by other factors of a physical or economic nature. The application of fertilizers, for example, may serve for a time to extend the crop-productive life of land against the inroads of erosion; or, similarly, high prices may for a time compensate for high costs of production on land depleted by erosion. In the former case, however, failure to control erosion will result eventually in the complete removal not only of the naturally fertile surface soil but of the subsurface soil which has been artifically fertilized. In the latter case, uncontrolled erosion eventually will make it uneconomic to attempt to produce from the land, regardless of prices, since it is physically impossible to grow crops on bedrock or fields too riddled by gullies for cultivation.

There is a definite interrelationship between erosion and economic and social ills. The incidence of erosion under our present economic order is influenced appreciably by fluctuations in prices. The level of prices and income has a definite relationship to erosion and to the undesirable economic and social disorders which usually come about where there are serious and damaging soil losses. Too often, high prices, even though prevailing for only a short period of years, foster land uses and practices which over a longer period of years prove inadvisable and uneconomical. Frequently low prices accompanied by serious agricultural maladjustments follow a period of high prices, and in these cases land uses and practices may be of an exploitative

[8] Economic and social aspects of soil erosion and soil conservation are discussed in the article, The Problem: The Nation as a Whole, pp. 84-110.

nature directed toward the end of meeting immediate overhead and costs of operation expenditures.

Where major alterations in the farm plant and cropping program are involved in the adoption of a conservation land-use system over a short period of only 1 to 3 years, immediate cash returns usually are reduced. In extreme cases, where, for example, a whole farm is highly vulnerable to erosion, adequate soil conservation might require the retirement of the entire farm from cultivation. In such cases, the landowner would have the alternatives (1) of slowing down the process of erosion temporarily by certain conservation measures, (2) of continuing production until the land was finally exhausted, or (3) of moving to land more suitable for agriculture.

On the other hand, it is frequently possible, under normal price and weather conditions, to shift from an exploitative to a conservative system of farming without reducing immediate income. The retirement of poor land from uneconomic cultivation and the concentration of operating outlays on good land that can be farmed economically, may, in certain cases, provide returns adequate to offset any immediate loss incurred by retirement of the poorer land from cultivation. Increased yields of wheat and sorghum, due to the conservation of water on good land by contour tillage, for example, has often offset the cost of retiring severely wind-blown acres in the southern Great Plains.

By and large, however, it is not unusual for the adoption of a soil conservation system to entail some reduction in immediate return. This fact, probably more than any other, is responsible for the resistance shown to soil conservation, particularly by those who have only a short-time interest in the land they operate, such as some types of tenants and speculator owners. Ordinary reductions in immediate income, however, will be offset by long-time benefits accruing from adoption of conservation practices. This is being shown by actual experience in the demonstration areas of the Soil Conservation Service throughout the country.

The social and economic implications of soil erosion and soil conservation are now under investigation by the Bureau of Agricultural Economics, in cooperation with the Soil Conservation Service. Until these investigations are complete, any discussion of this phase of the problem must be based largely on observations and field experience.

CONTROL OF EROSION

Since ancient times, men have been aware that rain and wind take soil from cultivated land. Throughout the world, some farmers have always sought, by one means or another, to prevent this loss.

In the hills above the ancient city of Antioch, in Syria, are the remains of erosion-control structures that probably antedate the Christian Era. In Peru 400 years ago, the Conquistadores found the Incas farming steep Andean slopes on terraces walled with stone, the cost of many of which, computed on the basis of present labor costs in the United States, would amount to $18,000 or more an acre. In Ireland, steeply sloping land is protected by stone "hedges" believed to have been built 5,000 years ago; and in Germany, the vineyards of the valley of the Rhine have been terraced for centuries. The Ifu-

gaos of the Philippines have produced good crops of rice for unnumbered generations on terraced mountain sides.

In the United States, alert farmers have tried to protect their land since the earliest colonial period (*137*). The first William Byrd, in 1685, described a deluge that carried away tobacco hills "with all the top of the manured land." By 1769, George Washington was experimenting with conservation farming practices at Mount Vernon. The Virginia school of experimental agriculturists, including Jefferson, Randolph, and Edmund Ruffin, devoted considerable attention to the problem. And Patrick Henry, soon after the Revolution, is said to have declared that "since the achievement of independence, he is the greatest patriot who stops most gullies."

But the concern felt by these colonial leaders, and by scattered farmers more obscure in station, failed generally to penetrate the ranks of agriculture. There was a misleading abundance of good land, for one thing; and there was no adequate mechanism for diffusing information. For nearly two centuries the average farmer was either unaware of or surprisingly apathetic toward the progress of destructive erosion in his fields. Conservation practices now regarded as fundamental in good farming failed to find a place in the operation of the average farm. Not until very recently did agriculture in the United States begin to regard soil conservation as being fundamental to sound farm practice.

Through the history of our agriculture, nevertheless, runs a thread of erosion-control effort. Many individual farmers were conscious of the problem and some tried remedies of their own. Gradually, the Department of Agriculture and a few States began to study the process of soil washing and methods looking to its control or prevention. Concern grew with knowledge, and culminated finally in the soil conservation program now being carried on by the Federal Government in cooperation with the States, various public and private agencies, and individual farmers. This program provides a basic pattern for permanent, cooperative effort in the field of soil and water conservation and represents an integral phase of national land-use activity.

Early attempts to control erosion tended to lean largely on a single method of control. In a number of States, principally in the Southeast, terracing[9] was regarded as a complete defense against erosion and was employed extensively. Terracing is an important measure in the control of erosion only if properly used. Used improperly, it may do more harm than good. The same is true of other control methods used alone under conditions which require a combination of measures. For example, in three States where a great deal of terracing has been done farmers recently judged unsatisfactory 70.7 percent of the existing terraces in one State, 91.6 percent in another, and 74.7 percent in the third. As rated by agricultural engineers on minimum specifications for modern terrace construction, 86.5 percent of the present terraces were unsatisfactory in the first State, 98 percent in the second, and 92.4 percent in the third.

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[9] Terracing as referred to here relates to the building of embankments at intervals approximately along the contour of slopes in order to intercept and dispose of run-off in such a manner as to reduce its erosion effect. Hillside ditching appears to have been the first step leading to the development of the present American system of terracing.

Until comparatively recently, vegetative methods of erosion control were given scant attention and only incidental application to the land. The use of mechanical and vegetative measures in support of each other was infrequent, and usually accidental. The fallacy of reliance on temporary or piecemeal methods of conservation, haphazardly applied, is demonstrated by the dust storms of the Great Plains, the abandoned, washed-out acres scattered over the country, the increasing damage of floods along many streams, and the numerous reservoirs filled or partly filled with the products of erosion.

The present-day concept of soil conservation, in contrast to the single-method approach, involves the integrated and systematic use of not one but many devices, applied in accordance with the peculiar needs and adaptabilities of the various kinds of land needing protection.

Essentially, soil conservation involves the adoption of a new and conservative system of land use, wherever the practices employed under the existing system fail to stabilize the land. Complete compatability between the pattern of human use and the pattern of natural environment is, of course, impossible. Man must have cotton, corn, wheat, and other products of the soil, and he must till the soil to obtain them. He must attempt, at the same time, however, to adapt his culture to natural limitations upon land use.

Quite aside from economic factors influencing the use of land, physical conditions of climate, slope, soil type, and extent and degree of erosion resulting from previous use of the land impose definite limitations upon the adaptability of every parcel of land to human use. Soil erosion is the result of man's failure to follow these limitations in using the land, or of his inability to do so because of economic pressure. Soil conservation requires a readjustment of land use in the light of these physical limitations so that each parcel of vulnerable land is treated with appropriate measures for erosion control, mechanical and vegetative, employed individually or in combination, according to the land's specific needs and peculiar adaptability to use. This is a new formula for conservation in the United States, based on the principle of land-use adaptability as established by natural laws. It offers the only feasible solution of the problem of soil and water conservation.

The present approach to erosion control through a planned system of land use involving the coordinate application of a variety of control measures has within 2 or 3 years very largely controlled erosion in numerous demonstration areas of the Soil Conservation Service. Simultaneously, flood crests have been lowered and the silt content of small streams draining certain of the areas has been reduced. In the Great Plains, practically all the rain falling on properly treated fields and pastures has been held in the ground, furnishing moisture for a cover of vegetation adequate to protect the soil from wind erosion. Moreover, in a number of instances, much or all of the rain that normally ran to waste through roadside ditches has been directed to useful purposes by diversion into fields and pastures.

There is ample evidence that on many of the demonstration areas, lands which a short time ago were declining steadily, along with the agriculture on them, are now well safeguarded from erosion. Further,

as a result of erosion-control work, many of these farms are moving steadily in the direction of increased yields per acre. In some cases larger profits have been due in part to better prices; but to no inconsiderable degree the upturn is the result of wiser land use and the reorganization of farm operations to achieve maximum efficiency in production.

An example of the major land treatment and farm reorganization procedure involved in a representative soil- and water-conservation project will partly illustrate the complexity of the program:

The Green Creek Soil and Water Conservation Project in Erath County, Texas, comprises approximately 30,000 acres and is fairly

FIGURE 10.– Soil defense by strip cropping, West Virginia.

representative of the West Cross Timbers section of approximately 7 million acres. The soils are predominantly sandy loam with clay subsoil; the topography ranges from moderately sloping to moderately steep and rolling. The land, for the most part, has been in cultivation only about 40 years.

The number of farms in the county decreased by 28 percent between 1910 and 1935. The value of farms in the county, including land and buildings, decreased by 53 percent between 1920 and 1935, and farm population decreased by 33 percent between 1910 and 1930.

Surveys in this watershed in 1935 disclosed the following conditions:

Thirteen percent of the area had been essentially ruined for cultivation by erosion, and approximately 50 percent of the topsoil of all the cultivated land had been washed or blown away. Many farmers were attempting to control erosion by terracing and by contour tillage of the terraced acres; some were doing nothing to defend their wasting fields. On 4,082 acres of terraced land on 103 farms in

the project area only 1.6 percent of the terraces were satisfactory and only 3 percent could be rebuilt to function properly. Of the cultivated land terraced prior to 1935, a total of 29 percent had been retired from cultivation or abandoned by the owners and operators because of erosion damage. An additional 18 percent of these terraced acres was retired when the 103 farms were placed under cooperative working agreements with the Soil Conservation Service.

Under these agreements an integrated 17-point program was employed to control erosion. It involved:

A. Detailed farm surveys of 217 farms, comprising 29,990 acres, including 132 farms actually cooperating in the watershed program.

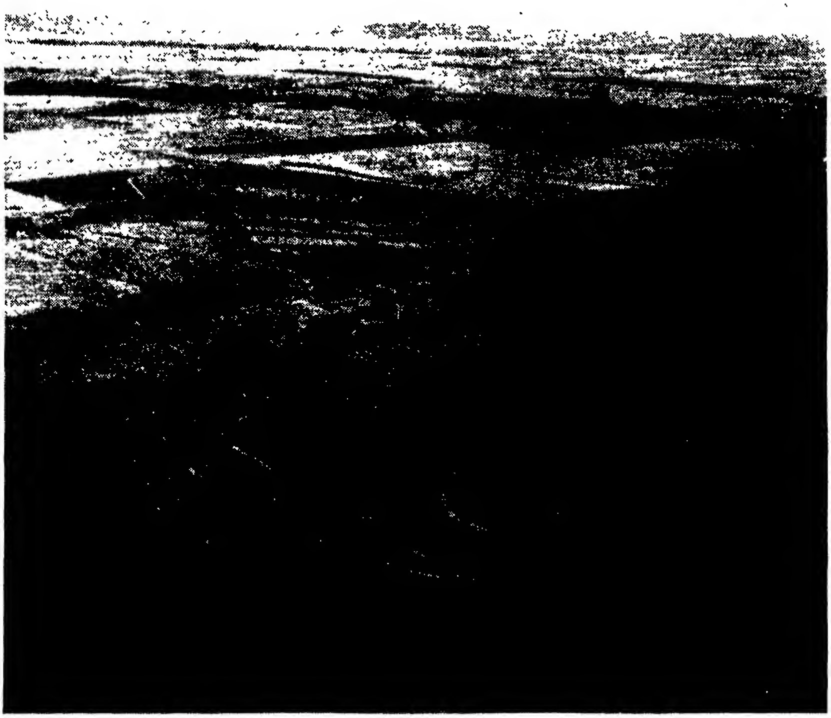

FIGURE 11.—Terraced fields near Pryor project, Oklahoma.

B. Joint preparation of detailed working plans for each farm by project conservation specialists and cooperating farmers, on the basis of the physical findings of the individual farm surveys.

1. Strip cropping (fig. 10).
2. Terracing of slopes ranging up to 5 percent, largely in conjunction with strip cropping (fig. 11).
3. Crop rotation.
4. Cover crops for seasonal protection of fields.
5. Retirement of severely eroded cultivated land to the permanent protection of grass or trees.
6. Contour cultivation (fig. 12).
7. Planting critically erodible areas to feed and cover plants for rehabilitation of wildlife.
8. Control of gullies, chiefly with grass.
9. Control of terrace outlets with grass.

10. Construction of small grassed channelways to carry water discharged from terraces safely downhill.

11. Development of meadow strips for safe disposal of excess run-off from terraced and contoured fields.

12. Pasture development by contour furrowing and reseeding.

13. Pasture improvement through rotation grazing, reduced grazing, and mixed grazing.

14. Combination of small fields into fields adaptable to contour cultivation, stripping, terracing, and other treatment necessary for adequate protection of soil and proper conservation of rainfall.

15. Construction of small reservoirs for continuous supply of stock water.

16. Planting black locust to protect erodible slopes and to provide an adequate supply of fence posts.

17. Field stripping to check wind erosion.

FIGURE 12.—Contour tillage in the humid regions. Each ridge is a dam, each furrow a reservoir for tapping water and storing it in the soil.

The mere enumeration of these major steps reveals very little of the coordination in their use. It fails to indicate how one measure supports another or how protection of one field provides protection to an adjacent field. However, since the establishment of these measures within the watershed, observations made by farmers, local business men, and the technical staff guiding the project reveal that for the first time in many years Green Creek did not overflow its banks during 1936, although 11 inches of rain fell in May and 10.9 in the last 14 days of September. Moreover, the creek ran during a greater number of days in 1936 than in 1935, although there was approximately 12 inches less rainfall, with unfavorable distribution.

Following is a list of the major accomplishments in the Green Creek area, as of August 1, 1937:

Cooperators .... number..	132
Acres in cooperating farms .... do...	19, 092
Area retired from cultivation to permanent protection with vegetation:	
Pasture .... acres..	1, 106
Meadow .... do....	194
Forest .... do....	64
Area protected by terracing, strip cropping, and contour tillage, combined .... acres..	4, 104
Area protected by strip cropping and contour tillage without terracing acres..	1, 148
Area protected by contour tillage alone .... do....	876
Area of pasture contour ridged, listed, or furrowed .... do....	3, 522
Area on which crop rotations were inaugurated .... do....	6, 199
Terraces and diversion ditches constructed .... miles.	240. 2

THE NATIONAL SOIL CONSERVATION PROGRAM

Conservation of the soil, in a national sense, requires the adoption of sound land-use principles and practices by agriculture as a whole. The attainment of this objective involves the widespread use of physical measures of land defense and the adjustment of certain economic and social forces tending to encourage exploitation of the soil.

The responsibility for such a national program falls upon both the Nation and the individual. National responsibility involves the protection of society's interest in a natural resource of vital importance to the people as a whole. Government functions properly in discharging this responsibility. Equally strong, however, is the interest of the individual in the land he owns. National action may be led and aided by Government, but the soil must be conserved, ultimately, by those who own and use it. The function of the individual in national soil conservation is to exercise the prerogatives of private ownership with conscious regard for the larger responsibility placed upon him by national interest in the soil resource.

The national program of soil conservation must be premised, then, upon a widespread understanding of the problem. Upon such an understanding will depend not only the incentive to act, but the ability to act intelligently. Demonstrations of sound conservation land-use practice carried out farm by farm in problem-type watersheds, through collaboration by Government and individual land users, have proved an effective and economical means of educating land users generally to an understanding of the problem of soil erosion and a knowledge of conservation methods. In this plan of demonstration, Government properly has exercised initiative.

Beyond this first phase of cooperative governmental action, however, is a second phase involving the extension of soil conservation practices to all vulnerable land. Here, demonstration is only partially adequate. The objective requires not only understanding on the part of the individual, but a mechanism through which he and other land users can cooperate voluntarily with one another and, if necessary, with Government, in the planning and execution of land-use programs. Individual effort to control soil erosion is likely to be ineffective; soil erosion is no respecter of fence lines and one man's failure to protect his fields may nullify the efforts of his neighbors. The very nature of the problem calls for cooperative action throughout an

entire watershed. Similarly, the individual may lack the technical knowledge necessary to plan an adequate farm program of erosion control and the equipment to carry it out. At the point where this lack impedes conservation, Government properly may step in with cooperative aid.

Recently the soil conservation district has emerged as a mechanism through which individual land users may exercise initiative in organizing to assist one another and in enlisting the cooperation of Government. Such districts, organized and empowered with essential authority under State law, open an avenue for joint action by the individual and Government which has been lacking heretofore. Through the machinery of these districts the resources of Government can readily be used to implement individual initiative.

Coincident with the physical treatment of land for conservation purposes, there must be adequate steps to alleviate or remedy certain economic pressures under which the individual landowner may be forced into exploitative methods of land use. Conservation agriculture is economical agriculture in the long run, but readjustments of land-use practice to conform with conservation principles may involve an immediate diminution of cash income or an increased operating outlay. Economic maladjustments of many kinds may operate to impair the ability of the individual to meet these possible temporary set-backs and, in some cases, to encourage continued exploitation. Such maladjustments must be ironed out, largely through remedial governmental action, if the individual is to be freed of the variety of stresses which cause him to mine the soil. Governmental effort is now directed toward a solution of these economic problems through such agencies as the Agricultural Adjustment Administration, the Farm Security Administration, and the Farm Credit Administration, as well as the Soil Conservation Service.

Governmental action along these several lines—in education, in assisting cooperative groups of land users, and in alleviating economic stress—must be all of a piece. Coordination here is essential to efficient leadership and effective results. All agencies of Government dealing with phases of the land-use problem must be regarded as an integrated whole functioning toward an identical objective. This coordination must extend not only to action programs but to the research activities upon which the science of sound land use depends for progressive development.

Research in relatively recent years has provided the factual basis for measuring erosion damage and rates of soil removal. Scientific knowledge is now far enough advanced to have determined that soil erosion is caused largely by man's misuse of the land; and, to a large degree, research has provided the basis for developing control methods within the resources and abilities of the average farmer.

The progressive development of knowledge through scientific investigation, however, should make it possible to control erosion more effectively and at a lower cost. Such studies will serve to answer questions that agriculture will be asking in the next 5, 10, and 50 years. Research must be extended outward to include agricultural regions about which we now have little basic knowledge, and downward to a more profound and fundamental understanding of factors

of soil and land use that together constitute the erosion potential. It must seek constantly to find new methods of conservation and to improve those now in use.

The requirements for a national program of soil conservation may be summarized as follows:

(1) Education to develop a widespread understanding of the problem of soil erosion and its control.

(2) Action by individuals and Government through a mechanism for close cooperation.

(3) Alleviation of economic maladjustments tending to impede adoption of conservation principles.

(4) Planned research to implement action with knowledge.

(5) Coordination of governmental effort in action and research phases of the program.

After generations of unconcern, this country seems now to be aware that soil erosion is a direct or contributing cause of land decline, outright land destruction, silt-filled stream channels, reservoirs, drainage and irrigation ditches, damaged highways and railways, and mounting floods. Extensive programs directed toward better land use and erosion control are now progressing under the leadership of the Department of Agriculture.

The work already accomplished, the constant development of newer and better methods of soil and water conservation through research and experience, and the increasing cooperation of land-owners and operators in accepting and adopting such methods, indicates a definite, far-reaching trend away from soil exploitation toward positive and continuing conservation. This movement must be sustained if a permanent agriculture for the Nation is to be insured.

IT HAS long been known that destruction of forests is one of the major factors in causing erosion on a large scale. By the same token, reforestation must be one of the major corrective measures. This article makes clear how forests protect the soil, gives striking examples of their efficiency, tells where forests should be used, and briefly surveys the present needs for reforestation in the United States.

Forests for Erosion Control

By E. N. MUNNS, JOHN F. PRESTON, *and* IVAN H. SIMS [1]

THAT forests are highly efficient agents for controlling erosion has long been an accepted fact. It was recognized in Europe a hundred years ago, was reiterated in the early reports of the Bureau of Forestry of the Department of Agriculture, and was one of the basic considerations leading to the acquisition of land for national forests in the Eastern States. The obvious truth of the fact is a matter of common observation by laymen and has been repeatedly demonstrated by experiments in which the soil eroded from forests, pastures, and fields has been carefully measured. Almost invariably soil losses from forests are among the lowest recorded.

Although the gross effects of forest cover are obvious, the conditions and processes involved are somewhat less well known. The layman usually considers the binding effect of the surface roots as the principal factor involved, whereas results of recent research indicate clearly that the protective influence of the litter is the key to the phenomenon.

Forest litter—the carpet of dead leaves, twigs, limbs, and logs on the forest floor—serves in several ways. Water falling as rain on bare soil dislodges silt and clay particles by its impact. These are taken into suspension and carried into the tiny pores and channels between the soil particles as the water makes its way downward. Very shortly the filtering action of the soil causes the openings to be clogged by the particles; water can no longer move downward through the soil, so it flows over the surface carrying with it the dislodged silt and clay; and erosion is actively under way. A protective layer of litter prevents this chain of events by absorbing the impact of the falling drops

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of water. After the litter becomes soaked, excess water trickles gently to the soil surface, no soil particles are dislodged, the water remains clear, pores and channels remain open, and surface flow is eliminated except in periods of protracted heavy rains.

In addition to this protective function the litter layer is in large measure responsible for the very porosity it protects. Within it lives a population of fungi, bacteria, and tiny animals that consume the litter and each other. The final product of the activities of this biotic community is the dark-brown colloidal substance called humus. This is carried downward into the mineral soil by percolating water and there surrounds the individual silt and clay particles, binding them together into larger grains and "crumbs." The spaces between these crumbs are larger than those between the individual particles, just as the holes between stones in coarse gravel are larger than those between fine sand grains.

The porosity thus achieved is supplemented and augmented by the channels left after the decay of dead roots. Many trees have roots extending 10 feet or more downward in deep soils, and when the trees die the roots decay, leaving veritable pipes to conduct water to deep storage. These deeply penetrating channels play an important role in preventing accumulation of water in surface layers.

The soil-binding function of the surface roots, so often observed by the layman, is of course highly beneficial in preventing soil washing. But here again careful research has shown that the densest network of roots is to be found in the lower portions of well-developed litter layers. The litter layer, then, is the essential part of the forest so far as erosion control is concerned.

In controlling wind erosion, the effect exerted by the tree crowns in reducing wind velocity is probably of primary importance, although the soil-binding action of the roots well-nigh equals it. Under conditions calling for the use of trees to control wind erosion, usually on sandy soils, the litter layer exerts a minor influence.

Some of the most dramatic examples of the effectiveness of forest cover for erosion control are furnished by cases where it has been suddenly removed. In southern California destruction of the forest cover by fire on steep mountain slopes is followed so regularly by destructive mud-and-rock flows that their occurrence and magnitude can be predicted with reasonable certainty. One particularly destructive flood of this kind in Los Angeles County carried from 50,000 to 67,000 cubic yards of debris from each square mile (640 acres) of denuded land. Adjacent forest land in the same storm lost about 3 cubic yards per square mile. Losses of 1,500 cubic yards per acre in single storms are fairly common in denuded areas. In contrast, losses from forested areas are reckoned in pounds per acre even during torrential rains.

In the northern Rocky Mountains replacement of dense forests by herbaceous growth following extensive fires coincided with major changes in stream behavior and the deposition of huge gravel and sand bars in the larger rivers, such as the Salmon in Idaho. Other observations in this State show that some 5 inches of topsoil was lost following severe fires in 1910 and 1919 on the Idaho and Bitterroot National Forests.

Less spectacular but no less significant, the results of experiments show how favorably forest cover shows up in contrast with other forms of land use. In the unglaciated portion of Wisconsin a 4-hour storm that yielded 2.4 inches of rain removed but 17 pounds of soil per acre from an ungrazed wooded area, and 745 pounds per acre from a grazed wood lot. A cleared and sodded pasture lost 220 pounds of soil per acre during the same storm. During the entire summer the protected forest yielded only insignificant quantities of soil other than in the storm cited above, whereas the cleared pasture lost a total of 600 pounds per acre and the wooded pasture 1,600 pounds per acre.

Equally striking examples are furnished by measurements in other parts of the country. In northern Mississippi, forest cover held soil losses to 75 pounds per acre during a storm period in 1931–32 that yielded 27 inches of rainfall, while cultivated fields were losing 34 tons per acre. During a 2-year period in the same locality, soil losses from cottonfields cleared of forest 4 years earlier were 195 and 69 tons per acre, respectively, under poor and good cultivation practice. In comparison with this record, erosion from a broomsedge field and a forested plot was negligible.

In central New York heavy spring rains washed more than 1,000 pounds of soil per acre from clean-cultivated potato fields but no measurable amounts from either grass or forested areas. The potato fields, moreover, had a slope of only 14 percent whereas the grassland and forest were on slopes of 20 and 27 percent, respectively.

Similar examples could be quoted from Texas, Oklahoma, and elsewhere. The magnitude of the erosional losses varies somewhat from region to region, but the relative effects of different vegetal covers and soil treatments always show the same relationships. Soil losses from forests are from 10 to 0.01 percent of those from cultivated fields and frequently are smaller than the losses from grassland.

WHERE FORESTS SHOULD BE USED

If forests are so efficient in controlling erosion, the question naturally arises, "Why not reforest all eroding areas and thus eliminate the evil?" The answer is that on part of the severely eroded lands forests cannot be established, and on another part proper soil-management practices will permit more intensive use of the soil while preventing or greatly reducing erosion losses. Some of the major conditions limiting the use of trees for erosion control are well known while others are local and in extent and hence less well recognized.

In general, forests do not occur naturally where annual rainfall is less than 15 inches, although the elfin forest or chaparral in California forms a heavy cover with less than 10 inches of rain annually. The droughty tendency of eroded soils therefore suggests that tree planting should be restricted to even more moist climates unless special cultural measures can be employed to nurse the trees through the establishment period. Recent successes in tree planting in the Great Plains, however, show that much can be accomplished in the extension of tree growth under marginal climatic conditions.

In spite of the climatic restrictions on the use of forests, nearly half the area of the continental United States did and will support

forest growth. Some of the more acute erosion situations, moreover, occur on lands that once supported forests but have been cleared for agriculture. Reforestation is, therefore, the intelligent as well as the obvious corrective measure to apply.

Locally, considerations of farm organization and economy, the kind and degree of erosion present, the need for protection of lowlands, the long-time prospect of markets, financial costs and returns, and, of late, considerations of wildlife management bear directly on the use of forests for erosion control. These factors, however, affect the choice only under the less severe or critical conditions. Where permanent, infallible protection is imperative, forests offer the only satisfactory answer.

In general, reforestation is the only feasible and permanent measure applicable on steep slopes and where low-lying fields of extremely high value are to be protected from flood-borne debris from steep slopes. On deep, erodible soils, subject to severe gullying, stabilization of gully walls may require permanent forest cover.

A special case illustrating the need for extreme protective efficiency is presented by the steep, unstable, cut-and-fill slopes created by modern highway construction. When the special problems of establishment have been overcome, trees have proved their ability to hold the soil on these steep slopes (usually 100 percent) against heavy precipitation. In nearly all cases, however, mechanical aids are required to permit the trees to become established.

When sheet erosion has removed all the topsoil, exposing the impervious, sterile subsoil, tree growth usually provides the only satisfactory control. To be successful, however, reforestation of such areas must be done with trees having low nutritional and water requirements. The composition of the original forest on such areas is no guide for the choice of species to use in reforestation. Failure to recognize and properly evaluate the nutritional level of eroded fields has led to many poor plantations and consequent disappointment in the performance of the forest. The isolated individuals in partially successful plantations are unable to stop the erosion process, primarily because they cannot form a continuous litter layer.

The major need for reforestation is probably to be found on areas permanently released from cultivation. Recent estimates indicate that there are now some 50 million acres in this category and that an additional 30 million will be added in the immediate future. About 21 million acres of these lands will have to be planted to trees for erosion control. Soil erosion is a process of major importance contributing to abandonment, and of course does not stop when cultivation ceases. Part of this area might, under proper methods of handling, continue on the fringe of profitable operation under existing economic conditions, but, in the main, costly trial and error has demonstrated that none of it is now needed in crop production. Devoting it to forest will not only preserve present values but will improve fertility and tilth in preparation for later use when agricultural demands justify it.

When there are alternative methods or types of vegetation to be used in controlling erosion, the habitat requirements of wildlife frequently dictate the choice. Small areas of cover, such as might be

provided by a clump of trees planted in a gully crossing a pasture or cultivated field, are now recognized as a highly desirable component of the environment for wildlife. The growing importance of farm game demands that adequate consideration be given its needs. This can usually be done at little or no increased cost or sacrifice when erosion-control plans are formulated.

PROTECTION OF THE FOREST IS ESSENTIAL

Whenever reforestation is selected as the method to be used for controlling erosion, a salient fact to be remembered is that the resulting forest must be protected if it is to perform its work adequately. The most common misfortunes befalling forests are to be burned over, to be overgrazed, and to be cut unwisely. Insects and disease sometimes must be combated, and occasionally sleet, snow, and windstorms play havoc with the trees. Of all these sources of damage, fire and grazing are the most dangerous and the most common. Both lead to loss of litter cover and porosity, compaction of the soil, thinning of the stand, and increased run-off and erosion. Some examples of the results, as determined by research, have been mentioned.

As the trees in plantations reach sizes suitable for posts, poles, and firewood, there is usually a temptation to utilize the materials. This can be done safely if cuttings are in the form of light thinnings from which the stand will recover promptly. Openings in the crown canopy should be small enough so they will be closed within 5 years.

Public agencies such as the extension services of the State agricultural colleges, State forest services, and bureaus of the Department of Agriculture are prepared to render advice on the care of erosion-control plantings and to suggest measures for the control of insects and diseases.

PRESENT ACTIVITY AND THE WORK AHEAD

With a growing recognition of the extent and intensity of the erosion evil, reforestation as a control measure is being employed more widely each year. In 1936, the Soil Conservation Service alone was responsible for the planting of some 114,000 acres. Of the remaining 426,000 acres planted in that year, probably some 20 percent, or 83,000 acres, was intended primarily or largely for control of more or less serious erosion. Data on the purpose of earlier plantings are not available, but it is unlikely that more than a third of the 31,000 acres planted by all agencies in 1934 was planted for erosion control. The twentyfold increase in the past few years, therefore, indicates the extent to which interest has been aroused.

Although present activity in reforestation is gratifying, it is not even keeping pace with land destruction and abandonment. Land is being released from cultivation at the rate of 1½ million acres a year, and at least half of this should be planted immediately. Of the 50 million acres of farm land already abandoned and the 30 million in process of abandonment, fully 11 million acres will not revegetate naturally and must be reforested to abate serious erosion. On perhaps another 10 million acres natural revegetation will be slow and erosion control will be the primary, though not the sole reason for reforestation. The history and present condition of these areas point

toward the conclusion that this rehabilitation will be largely up to the public. The lack of agricultural value of these lands and the extent of owner interest in them is disclosed by the very fact of abandonment. On these most seriously eroding lands, moreover, reforestation costs will be highest and future returns low. There is, therefore, little or no stimulus to private initiative to assume responsibility for the job. What is needed is an aggressive program of public acquisition in regions where abandonment is extensive and erosion is severe. The Piedmont Plateau from Virginia to Texas, the bluff lands bordering the Mississippi, the Appalachians, and other less extensive regions are estimated to contain at least 22 million acres of formerly tilled land which should be in public ownership as a safeguard against the erosion menace (table 1).

Table 1.—*Areas proposed for public acquisition, and areas requiring restoration of cover for watershed protection* [1]

Drainage	Areas to be acquired			Areas requiring restoration of cover	
	Submarginal agricultural land	Forested land	Total	To be reforested	To be otherwise revegetated
	Thousand acres	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*
Northeastern	900	6,900	7,800	500	
South Atlantic	3,300	15,500	18,800	2,000	
East Gulf	4,600	15,400	20,000	1,000	
West Gulf	400	1,900	2,300	250	
Lower Mississippi	1,200	4,600	5,800	250	
Arkansas—Red	2,200	17,000	19,200	750	
Ohio Valley	6,000	22,600	28,600	4,000	
Upper Mississippi	2,500	4,600	7,100	500	
St. Lawrence	300	700	1,000	500	
Missouri	400	7,200	7,600	1,000	150
California		10,000	10,000	75	100
Colorado		2,800	2,800	150	200
Rio Grande		5,000	5,000	50	50
Great Basin		1,800	1,800	50	200
Columbia		12,400	12,400	150	200
Pacific Cascade		5,000	5,000	100	
Total	21,800	133,400	155,200	11,235	900

[1] From A National Plan for American Forestry (*432, v. 2, p. 1533*). [2]

The need for reforestation of abandoned land is admittedly great, but the need for similar treatment of submarginal land still in cultivation or of those parts of farms unsuited to further agricultural use is at least equally acute. Some 8 million acres fall into this latter class and here the program should be directed less toward acquisition and more toward assistance in the form of analysis of local needs, expert advice on methods and species to plant, provision of planting stock, and active aid in protecting the plantations established.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

SINCE destructive erosion results from upsetting nature's balance, there is much emphasis today on studying nature's method of erosion control. In this, grass and other thick-growing vegetation are enormously important. Close study of the effects of such vegetation is giving us some surprising new side lights on what it actually does in conserving soil and water, as this article shows. The authors also tell how to obtain the best results from a vegetative cover in actual farming practice. A final table lists promising plants now being developed in nurseries, with remarks about their qualities and adaptation.

Grass and Other Thick-Growing Vegetation in Erosion Control

By C. R. Enlow *and* G. W. Musgrave [1]

THE development of agriculture in the United States since the date when statistics were first gathered on livestock, grazing lands, and croplands presents an interesting picture from the standpoint of permanent and profitable production of livestock and the conservation of soil and water. It is generally recognized that the grasslands of this country were in splendid condition a few decades ago (figs. 1 and 2); today the original cover has disappeared from much of this area and been replaced by cultivated crops or inferior native plants.

In the Atlas of American Agriculture (*354*),[2] the distribution of native grazing grasses in the Corn Belt, the Great Plains, and throughout the West is shown on a map dated 1923. The information given on this map undoubtedly was collected over a period of years previous to 1923, so that the distribution shown represents in some degree the original areas occupied by tall grasses, short grasses, and the other types that made up our former grass population. A close study of the country's grasslands today shows the kind of changes that have taken place in the last several years, chiefly as a result of man's activities (fig. 3). In the Pacific Northwest west of the Cascade Mountains, the natural pastures are producing less forage with every passing year, owing to the practice of burning, the declining fertility of the soil, the losses resulting from erosion, and the encroachment of weeds, weedy grasses, and brush. It is now difficult to find extensive areas of the bunch wheatgrass that formerly prevailed over much of the Pacific Northwest east of the Cascades, as these plants

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Figure 1.—Looking out over the Great Plains in 1870 (Natrona County, Wyo.). This stand of valuable grazing plants—needlegrass (*Stipa* sp.), dropseed (*Sporobolus* sp.), grama (*Bouteloua* sp.), western wheatgrass (*Agropyron smithii*), and others—is typical of the virgin condition of the Plains. Note the absence of sagebrush, an undesirable species that is prevalent today. (Photograph taken in 1870 by W. H. Jackson, Hayden Expedition.)

Figure 2.—A view of the Gila River watershed in Arizona when the white man first came to that country, showing the type of grass cover. The species principally in evidence is galleta (*Hilaria jamesii*). (Photograph taken in 1870 by W. H. Jackson, Hayden Expedition.)

have been largely replaced by sagebrush and annual grasses. The former extensive areas of galleta and sacaton in the Southwest have been displaced by the undesirable creosotebush, sagebrush, annual grasses, and weeds, and much of the land is actually without cover of any kind. The native short grasses, grama and buffalo grass, now extend into eastern Nebraska, Oklahoma, and Kansas, whereas they are shown on the map mentioned above only in the extreme western portions of these States and in eastern Colorado. The tall grasses of the Corn Belt have been plowed up for crop production or displaced entirely by Kentucky bluegrass, redtop, and other cultivated grasses. Many of the former excellent bluegrass pastures of the Northeastern States are today occupied by poverty grass, weeds, and brush

FIGURE 3.—Band of Navajo sheep and goats near Cow Springs, western Navajo jurisdiction, November 1934. The sheep are of the old Navajo type. Grass has almost disappeared as the result of heavy and continuous grazing.

Many factors undoubtedly lie behind the changes that have taken place. In the humid regions probably the principal cause is simply depleted fertility. In the Great Plains and throughout the semiarid West, however, the changes are due primarily to improper management of grasslands and failure to conserve the necessary moisture.

MANAGEMENT FOR LIVESTOCK PRODUCTION

Grazing experiments with beef cattle conducted by the North Dakota Agricultural Experiment Station and the Bureau of Plant Industry have been under way at Mandan, N. Dak., for 20 years.[3] On a continuously grazed pasture, using 10 acres for every head of livestock, the average seasonal gain has been 311 pounds per animal, or a daily gain of 2.1 pounds per head. On pastures stocked at the rate of 7 acres per head, the seasonal gain has been 308 pounds, and the daily gain 2.08 pounds per head. On continuously grazed pastures of 5

[3] SARVIS, J. T., THE COOPERATIVE GRAZING EXPERIMENT. N. Dak. Agr. Expt. Sta. Cir., 2 pp. 1937. [Mimeographed.]

acres per animal, the average seasonal gain has been 234 pounds, with a daily gain of 1.67 pounds per head; and with 3 acres per animal, the seasonal gain has been 160 pounds per head with an average daily gain of 1.47 pounds.

Although it is evident from these figures that the individual animal gained more weight under the lighter rates of stocking, the gain per acre of land is seen to be larger under the heavier rates. The significant point, however, lies in the fact that the pastures stocked at the rate of 5 and 3 acres per head could not be grazed in the season of 1935. This shows that in the low-rainfall areas of the West, the grasses are not able to survive extremely dry seasons when closely and continuously grazed. If permanent pastures are to supply feed, the reserve strength of the grasses must not be so exhausted that the growth fails in critical periods. Another important and significant consideration is the gain per animal during the season. It will be recognized at once by all livestock men that the animals that make a heavy gain are in excellent condition and will bring a much higher price per pound when marketed. A smaller number of livestock also represents less total investment and lessens the danger of an extreme feed shortage.

For 18 years during the above experiment, livestock were grazed on rotation pastures at the rate of 5 acres per head. This resulted in a seasonal gain of 269 pounds per animal or a daily gain of 1.84 pounds. This significant increase over the figures for continuous grazing at the same rate of stocking is a further indication of the importance of giving grasses a chance to replenish exhausted reserves. It is generally recognized that grasslands, if properly grazed, present no serious menace from the standpoint of erosion. This points to the fact that permanency of usage should result from a lighter rate of stocking.

Similar results were obtained in a grazing experiment conducted by the Bureaus of Animal Industry and Plant Industry at Ardmore, S. Dak. (*35*). The average rate of gain per animal over a 10-year period with 11 animals grazing on 150 acres was 220 pounds. In comparison, an 80-acre pasture grazed during the same period by 11 animals produced an average gain of only 161 pounds. Still another pasture of 160 acres was grazed alternately, utilizing 80 acres from the beginning of the season in the spring—about May 21 until August 1—while the other 80 acres was grazed from August 1 to the end of the season—October 18 or earlier. This method of grazing, using 24 animals the first 5-year period and 16 animals the last 5-year period, produced a gain of 200 pounds per animal per season during the first 5 years and 173 pounds the last 5 years, showing conclusively that such a method of grazing gives a greater gain per animal. In the last 3 years of the experiment, steers on pastures alternately grazed made a significantly greater gain per animal than steers on pastures grazed continuously at the same rate of stocking. The gains per acre were likewise significantly greater in alternate grazing.

Conclusions concerning the effects on the vegetation from the experiments at the Mandan station are that native grasses deteriorate when grazed too early in the spring if subjected to continuous and close grazing. The dominant plant species in the pastures are blue

grama (*Bouteloua gracilis*), needle-and-thread (*Stipa comata*), and two sedges (*Carex filifolia* and *C. heliophila*). At Ardmore, S. Dak., no bad effects from close grazing of the principal grasses, buffalo grass (*Buchloë dactyloides*), blue grama, western wheatgrass (*Agropyron smithii*), and plains bluegrass (*Poa arida*), were noticeable during the life of the experiment.

The Kansas Agricultural Experiment Station has results from grazing experiments comparing deferred grazing with continuous grazing of bluestem pasture land (*6*). In these experiments deferred grazing required 3.43 acres per head and continuous grazing 4.93 acres per head. The average gain per acre was 84 pounds for deferred grazing and 54 pounds for the continuous usage. The stand of desirable grasses improved under the deferred system and showed no improvement under continuous grazing. These experiments indicate that proper management of grassland is definitely a profitable undertaking.

There are many instances where western ranchers, having recognized the advantages of light or moderate grazing of grasslands, are now following such practices with a high degree of success. One rancher in Texas is grazing 20 head of cows per section while his neighbors are grazing 30 per section. He gets as many calves from 20 cows as his neighbors get from 30 cows and his pastures are in much better condition. A rancher in Colorado, recognizing the importance of maintaining an abundance of feed at all times, has built up a very profitable enterprise through proper treatment of his grasslands and is today producing much more beef per acre than his neighbor. When it is generally recognized that grasses must be treated properly if they are to endure as a source of animal nutrition, a permanently profitable grazing industry will be possible and soil erosion on grasslands will become a minor or nonexistent problem.

EFFECTS ON SOIL AND WATER CONSERVATION

Nature's method of protecting the land surface by a mantle of vegetal cover has, of course, been highly successful. Perhaps it was not realized just how effective such a cover can be until the pioneering studies at the University of Missouri showed the great difference in measured losses of soil and water from land in grass and from land in cultivated crops. These studies, inaugurated under the direction of M. F. Miller in 1917, showed that only about 11½ percent of the rain that fell was lost from sod but more than 27 percent ran off from cornland. They also showed that the rate of loss was such that it would require only 56 years to erode 7 inches of surface soil when the land was in corn continuously, but more than 3,500 years with the land in permanent sod.

Subsequently, similar studies have been undertaken on many different soils and land slopes and in regions having different rainfall characteristics. These have shown without exception very wide differences in soil and water losses from cultivated land and from land under a protecting mantle of close vegetation. The results from such studies at nine different locations and upon as many different soil types are given in table 1. In each of the cases shown the row crop is either corn or cotton and the grass is bluegrass or Bermuda grass. These measured differences bring out several inter-

esting points. The run-off of surface water in all cases is very much less from the land in grass than from that in cultivated crops. However, on grassland the reduction in erosion is even greater and the annual soil losses are practically insignificant in amount. Furthermore, the density of run-off, or the amount of soil carried by a given volume of run-off, is very much less from the grass cover. Thus, while the close vegetation has effected a substantial control of surface run-off, it has exerted an effect in the control of erosion that is many times greater.

Table 1.—*Soil and water losses from grass and row-spaced crops on various soil types and land slopes* [1]

Soil	Location	Slope	Run-off		Erosion per acre		Density per cubic foot [2]	
			Row crops	Grass or pasture	Row crops	Grass or pasture	Row crops	Grass or pasture
		Percent	*Inches*	*Inches*	*Tons*	*Tons*	*Pounds*	*Pounds*
Vernon fine sandy loam	Guthrie, Okla	7.7	4.71	0.407	24.29	0.032	2.841	0.0551
Shelby silt loam	Bethany, Mo	8.0	9.85	3.24	68.78	.29	3.847	.049
Clinton silt loam	La Crosse, Wis	16.0	7.11	.96	88.67	.03	6.871	.0172
Dubuque silt loam	do	30.0	6.99	2.77	81.44	.245	6.419	.0487
Marshall silt loam	Clarinda, Iowa	9.0	2.32	.26	18.82	.06	4.469	.1271
Houston black clay	Temple, Tex	4.0	4.66	.013	23.83	.03	2.817	1.271
		2.0	4.67	.332	10.62	.102	1.253	.169
Cecil sandy clay loam	Statesville, N. C	10.0	4.62	.154	22.58	.012	2.693	.043
Kirvin fine sandy loam	Tyler, Tex	8.75	8.54	.47	27.95	.124	1.803	.145
		16.5	6.29	.099	72.04	.008	6.310	.045
Nacogdoches sandy loam	do	10.0	6.98	.224	8.18	.006	.646	.015

[1] Data from Soil Conservation Service experiment stations, annual averages.
[2] Pounds of soil contained in 1 cubic foot of run-off.

Apparently these results mean that the grass is doing several different things in the way of providing protection to the land. It is of interest to note and examine some of these separate effects.

Interception of Rainfall and Surface Protection

Probably one of the important ways in which close vegetation protects the ground surface is through the interception of some rainfall by the plant surfaces, in the same manner in which a dense pine forest prevents much of the rain from reaching the ground surface. Although there is not much information at present available on the exact extent of this interception by various kinds .of vegetation, preliminary studies have shown that as much as one-half inch of rain may be retained upon the leaves and stems of a good stand of alfalfa or clover. Grass may be nearly as effective in this respect (*275*).

Another important effect of close vegetation is that of protecting the soil surface from the beating action of dashing rains, which normally cause surface water to become very muddy. Even the water that eventually reaches the ground surface beneath a mantle of close vegetation has had its force broken. This is important, because it has been shown that a soil may absorb clear water at a very much higher rate than it can take in turbid or muddy water.

In pioneering work on this subject Lowdermilk (*222*) showed that by applying to soils water containing 1.7 to 1.9 percent of solids, the rate of percolation diminished within 6 hours to less than one-tenth the rate for clear water.

Investigations show in all cases a marked reduction in the silt load carried by run-off from grassed areas when compared with that from cultivated areas. Frequently the run-off from grassed areas is crystal clear, while at the same time and from the same rain run-off from land under cultivation is heavily loaded with silt.

Effects of Organic Matter

Still another effect of keeping land in grass or close vegetation a fair proportion of the time is the maintenance in the soil of a comparatively high content of humus or organic matter. Cultivation is

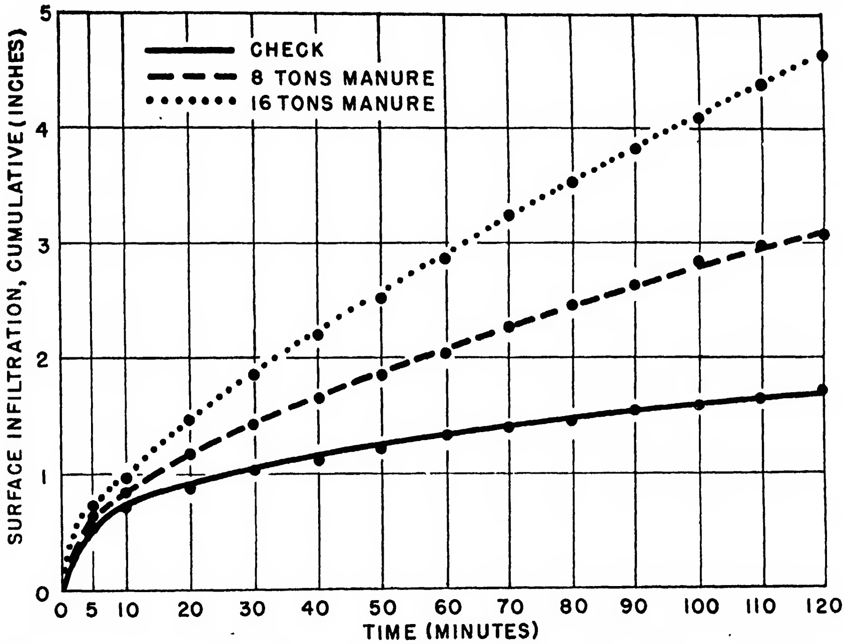

FIGURE 4.—The effect of organic matter upon the rate of water penetration into Clarion loam.

known to destroy soil organic matter rapidly. Grass cover—as well as good crop rotation—tends to maintain a normal or high content of this valuable material.

The importance of this is seen in studies of the rate of water absorption by soils rich in organic matter and by soils deficient in this respect. Smith, Brown, and Russell (*366*) have shown that soils high in organic matter may have a rate of water penetration more than double that of soils with a low organic matter content (fig. 4).

Because of this increased rate of water intake in soils high in organic matter, there should be a marked reduction in the amount of run-off. That this is the case has been proved beyond doubt. The results

from one such experiment are given in table 2. In this experiment the effect was measured both on fallow land and on land in crops. The fact that run-off was reduced from 17½ inches of water to about 13 under a fallow or uncropped condition by the addition of organic matter is definite proof of the effect of added organic matter upon the physical character of the soil. In the cropped portion of the experiment, the treatment cut the total run-off approximately in half. Thus, the effect under these conditions is proportionately greater than under the fallow condition, and this is undoubtedly due to the effect of the treatments upon both the soil and the crop. The organic matter has improved the soil and those physical properties that affect the rate of water intake; in addition, it has increased plant growth so that the total amount of water interception is greater than on untreated plots. Besides these effects upon run-off, corresponding effects upon erosion were found, and the treatment, even in the absence of a crop, reduced soil losses from about 190 tons to approximately 130 tons per acre for the period of the experiment. In the presence of a crop, the soil losses were about one-third as great from the land high in content of organic matter as on the corresponding check areas less rich in this material.

Table 2.—*Effect of incorporation of organic matter on run-off from fallow soil and cropped soil*[1]

Soil and treatment	Total run-off: Amount	Total run-off: Density per cubic foot	Erosion per acre	Soil and treatment	Total run-off: Amount	Total run-off: Density per cubic foot	Erosion per acre
Fallow:				Cropped:			
	Inches	*Pounds*	*Tons*		*Inches*	*Pounds*	*Tons*
Fallow and sweet-clover [2]	13.20	5.64	135.17	Corn and sweet clover [2]	4.75	1.97	17.34
Fallow and manure	13.05	5.49	129.93	Corn and manure	4.87	2.83	24.95
Check	17.50	6.01	190.73	Corn (check)	9.25	4.60	77.41

[1] Experiment 3, Aug. 31, 1932, to Dec. 31, 1935, at Clarinda, Iowa. Precipitation: 96.54 inches, total; 62.27 inches effective.
[2] Plowed under in amount equivalent to the manure application.

Effects on Velocities of Surface Run-Off

Secretary of Agriculture Henry A. Wallace once said that the aim in protecting our fields against erosion is to make the water "walk off" and not "run off." Close vegetation, such as grass, has a definite effect on run-off water, causing it to move in thin sheets across the land surface and to proceed more slowly than it does across land in cultivated crops. Unconcentrated water moving across a meadow does not have the opportunity to achieve such high velocities as water moving down slope between the rows of cultivated crops. Because of the slower movement, it possesses less cutting power. This is another reason for the very slight erosion that occurs under an ample vegetal cover.

Still another effect of the retarded movement is that of providing a greater amount of time for water to penetrate into the soil. This is

indicated in the results of an experiment in which the run-off from 43 effective rainfalls (on Marshall silt loam on a 9-percent slope) was measured from corn and bluegrass, from July 1, 1934, to December 31, 1935. The data show that the run-off from bluegrass on a slope 3 feet long was 6.59 inches, about two-thirds as much as that from corn on a corresponding slope (9.81 inches). However, on a longer slope (72.6 feet) the run-off from the bluegrass was only 0.50 inches, one-tenth as much as from corn (5.07 inches) under otherwise exactly corresponding conditions. Clearly, the greater control exerted by bluegrass on the longer slope is due, at least in considerable measure, to the fact that the retarded rate of movement under the grass has permitted a much greater time for water penetration on the longer slope than on the shorter one.

Effects of Plant Roots

That plant roots have a great protective influence in binding soil particles together has been demonstrated by the work of Weaver and Harmon (*453*). Weaver applied water artificially to sod of different kinds and to soil taken from a field that had been planted to corn for a period of 7 years. He found that the length of time required for artificial rains to wash away the soil varied widely, as shown in the following tabulation, but that it was very much less for the bare soil that had been in corn, and also for the soil held only by the roots of annual weeds, than for that held by the roots of perennial grasses. More than likely similar results would be found in studies dealing with a great many other kinds and species of plants. Existing evidence shows that erosion from a field of corn with good plant development is less than from a similar field where the plant has been limited in growth by drought or other unfavorable conditions.

Cover and treatment	Erosion time Hours	Minutes
Big bluestem (*Andropogon furcatus*)	2	40
Big bluestem and Indian grass (*Sorghastrum nutans*), ungrazed	3	28
Big bluestem and Indian grass, grazed	2	35
Little bluestem (*A. scoparius*), ungrazed, mowed annually	3	32
Little bluestem, grazed	2	40
Nettle grass (*Stipa* sp.), ungrazed	3	20
Bluegrass (*Poa pratensis*)	4	20
Annual weeds, including wire grass, fetid marigold, and stinkgrass		41
Barren soil from cornfield		18

Weaver (*222*) says:

> The living plant materials form a wonderfully efficient anchorage system for the soil, especially the surface layer. This living network, which holds the soil in place, constitutes about one-tenth, by weight, of the total organic matter in the surface 6 inches.

How to Obtain Best Results From Vegetal Cover

To control erosion by vegetal cover, it is desirable:

(1) To have a kind of plant that provides a thorough cover of the ground surface and a fairly large leaf area to intercept rainfall and to protect the ground from the impact of beating rain.

(2) To provide conditions favorable to the development of the plant so that it can grow with normal vigor and reach full maturity.

(3) To plan the management of the land and the proportion of time devoted to clean-tilled crops or close vegetation in such a way as to permit the accumulation

of an adequate supply of organic matter and to guard against the exhaustion of this valuable component, which commonly results when land is intensively or continuously tilled.

PRACTICAL DEVELOPMENTS ON FARMS

Uses of Grass and Close-Growing Vegetation

The final test of the use of vegetation in erosion control and practical farm economy is its actual application on the farm. The recently initiated soil conservation program has brought grass and other close-growing vegetation into practical use in many ways on thousands of farms throughout the country. Strip cropping is undoubtedly one of the most important, but as it is discussed elsewhere (pp. 634–645), it will be omitted here. Close-growing vegetation is also used in vegetated waterways, buffer strips, gully control, rotations, terrace outlets on grasslands, and for reseeding cropland or abandoned land. All of these practices and devices have been used on farms in localized areas for many years. Now an attempt is being made to put them into use on a Nation-wide scale.

The removal of surplus water from cultivated fields has always been a serious problem, largely neglected in the past except where gully formation has been so serious as to threaten the existence of farm land or buildings. Vegetated waterways are merely natural depressions that have been seeded or allowed to revegetate naturally with permanent grass, alfalfa, alfalfa-grass mixtures, lespedeza, or other cover, and thus protected from gully formation or any excessive soil loss (fig. 5). Such waterways, if properly handled, make excellent permanent hay meadows, and in most cases actually build up with soil instead of permitting erosion. The installation is simple, inexpensive, permanent, and of practical benefit to any farm. Where a farm is terraced or to be terraced, these waterways offer the ideal means for carrying away surplus water.

Frequently it is both necessary and desirable to cultivate sloping land, and a high percentage of relatively steep land is maintained in cotton, corn, potatoes, or other crops requiring clean cultivation. Erosion can be reduced to a minimum by planting the cultivated crops on the contour or level, separating the field into strips by planting narrow bands of grass, alfalfa, kudzu, or other close-growing crops. These bands also are on the contour and can take up any irregularities of the land, thus avoiding point, or short, rows in the cultivated crops. Such strips of permanent vegetation act as buffers or filters, tend to keep surplus water from concentrating and cutting gullies, and aid materially in keeping the soil on the field. They also are a permanent source of hay, or can be grazed after the tilled crop is harvested.

The importance of vegetation in gully control can scarcely be overestimated. The early program of the Soil Conservation Service consisted largely of gully control by mechanical structures, but these are used at present only to aid the establishment of vegetation and eventually secure vegetative control. Trees and shrubs, as well as grass and legumes, are very effective in bringing about gully stabilization, but generally are not desirable in cultivated fields. Most field gullies can be stabilized with ordinary grasses and legumes if proper methods of fertilizing and seeding as well as correct kinds of vegetation are

used. Quite often, gullies will stabilize naturally if protected by fencing so that natural vegetation can grow undisturbed by grazing animals.

The value of a regular system of crop rotation, including cash crops and close-growing grass or legume crops for maintaining yields has been recognized for many years. If the rotation plan is carried a step further and based on proper land use, including contour cultivation and complete or modified strip cropping, the problem of erosion

Figure 5.—Waterway with a heavy growth of bromegrass (*Bromus inermis*) after the severe drought of 1936. Before a 2-inch rain that fell about 2 weeks prior to the date of this picture, the grass was dormant. Bromegrass is palatable and makes good hay. It also protects the soil against erosion.

control becomes greatly minimized. In addition to the soil-conserving ability of grass while actually occupying land, the roots remain in the soil after the land is broken and aid materially for several years in preventing both water and wind erosion. Rotation brings this conserving effect into play on all land under treatment.

The disposal of water from a terrace system is frequently a serious problem, particularly if it is not given proper attention before terrace installation. On many soil conservation projects, the engineers have planned the terraces so that they empty on permanent grass pasture or meadow, with very little fall at the outlet. The surplus water from the terrace system can be used to advantage on the pasture land for flood irrigation, through the construction of contour furrows, level irrigation ditches, or other mechanical devices.

Millions of acres of cropland in the United States has been abandoned, mainly because of water or wind erosion. Much of this land has lost its entire topsoil so that continued production of crops on it

is unprofitable. Enormous areas have been made inaccessible by gullies while other areas have been seriously damaged by wind erosion and in some cases made worthless by the resultant formation of sand dunes.

A large portion of these lands has been revegetated naturally by weeds, grasses, shrubs, and trees, but on extensive areas reseeding is advisable to gain immediate control and to obtain some economic return. In humid regions, fertilizers are invariably a prerequisite to successful revegetation with desirable plants, and considerable care is necessary to establish a satisfactory growth. It has not been generally recognized that grasses respond to lime, phosphate, nitrogen, and potash as do cultivated crops, and many seedings have failed as a result of improper treatment. Further, the preparation of a good seedbed, seeding at the proper time, rate, and depth, and frequently improvement by the addition of manure or plowing under a cover crop are necessary for success. In semiarid regions, reseeding of former croplands is much more difficult, owing to the lack of plants adapted to artificial seeding under such conditions and to the uncertainty of soil-moisture conditions being favorable to germination and the survival of seedlings. Crested wheatgrass, smooth bromegrass, sweetclover, slender wheatgrass, and a few other plants have been used with much success in the northern semiarid States, but no commercially available plants are suited to the southern States of the region. Several native and introduced plants that show promise have been seeded successfully in a limited way, but much work is needed both in improvement of plants and methods of planting.

Mechanical Devices to Aid Vegetation

Mechanical devices are particularly desirable in establishing vegetation where (1) the conservation of limited rainfall is necessary to get enough moisture in the soil to secure proper germination and subsequent plant growth and (2) when the soil and type of precipitation lead to severe sheet or gully erosion that interferes with the establishment of good stands by soil washing during the germination period or before the young plants become well established.

Of the various mechanical devices that have been tried on grasslands to conserve moisture and soil, simple contour furrows and ridges have proved the most successful and the least expensive, and are particularly suited to semiarid climates or droughty soils in more humid areas (fig. 6). Hundreds of thousands of acres have been treated on farms in soil conservation projects throughout the country, but the practice is spreading to farms outside projects more rapidly in the Great Plains region than elsewhere. Furrows and ridges of all types have been constructed, ranging from terraces to small furrows or ridges closely spaced and made with an ordinary turn plow or modified lister. The general tendency is toward construction of smaller furrows or ridges that can be made with an ordinary farm implement, with close spacing to attain proper distribution of moisture and a relatively uniform grass cover. Furthermore, small structures offer no interference in mowing for weed control or in utilization of the crop. When furrows and ridges are small, machinery or vehicles can be moved over grasslands as desired.

Contour furrows are not an innovation. They were used successfully in South Africa as early as 1876, and in Texas in the 1880's on grassland since plowed for wheat production. The Spur, Tex., Experiment Station has secured some very interesting results showing the

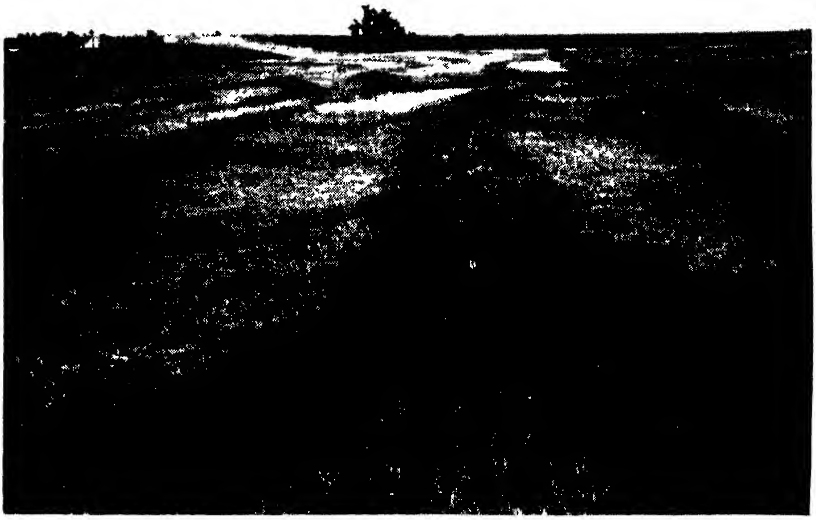

FIGURE 6. -Increased growth of grass due to contour furrowing of pasture. (Ira L. White farm, Jewell County, Kans.)

advantage of solid contour listing on buffalo-grass land. Increases in yields and moisture penetration in the soil are given in table 3.

Table 3.—*Increases in grass yields and moisture penetration resulting from contour listing of buffalo-grass sod at the Spur, Tex., experiment station*

Treatment	Dry grass per acre		Moisture penetration (Oct. 17, 1936, following 11.13 inches rainfall in September)	
	1935	1936	Penetration into soil	Rainfall absorbed
	Pounds	*Pounds*	*Inches*	*Inches*
Solid contour listed in 1934	2,423	2,315	72	6.67
No treatment	857	592	30	2.10
Solid contour listed in 1936		1,326		

There is some disagreement among those working with furrows and ridges regarding their relative value, but both are successful under certain conditions. Ridges may be used successfully in areas that will support a grass that will cover them a short time after construction; this is necessary to prevent breaking during heavy rains. Ridges seem

better adapted to fairly level land, with a slope of not more than 3 or 4 percent, where it is possible to impound quite heavy rains without appreciable loss. Contour ridges approximately 12 inches high and 20 feet apart on fairly level grassland at San Angelo, Tex., held an 18-inch rain that fell in 3 days without appreciable loss of moisture.

Contour furrows are widely favored because the difficulty in revegetation is less. In some cases only a small ridge is made; in others, the soil is entirely dispersed by spreading the furrow slice over adjoining land; and in still other cases, the furrow slice is placed grass-side up so that bare soil is exposed only in the bottom of the furrow. Various machines that show much promise for making both furrows and ridges are under construction or being tested at present. Regardless of the future trend in construction, excellent results have been obtained everywhere from both furrows and ridges in conserving soil and moisture, increasing penetration of moisture into the soil, and stimulating increased production of grasses.

The construction of dams is of little value in the soil conservation program on grasslands, except as a means of attaining better distribution of livestock on range lands by rearranging the sources of water supply. In those parts of the West where the topography is favorable, excellent results have been obtained by spreading water from the spillways of dams over large acreages, increasing the production of vegetation by several hundred percent. Such increased production materially aids erosion control by lessening the grazing load on adjoining range, provided it is possible to keep ranchers from increasing the number of livestock grazing on the land. Spreading the water is accomplished by the construction of a series of level irrigation ditches, levees, dykes, or other mechanical devices.

Pasture Improvement With Fertilizer, Lime, and Seed

As mentioned previously, the need for fertilizer on grasslands in humid regions is almost universal. Throughout the Eastern States and in humid or irrigated sections of the West, phosphate gives excellent results by increasing production and thickening the grass turf. Lime is likewise beneficial over much of the same area, while potash produces an increase in many cases. The need for nitrogen, as for phosphorus, is almost universal in humid regions, but it is doubtful if the expense of applying commercial nitrogen to grasslands can be justified except in dairy farming. Barnyard manure can be used profitably wherever available.

Reseeding old pastures is a definitely important practice in humid regions, particularly where white grubs have seriously injured turf previously weakened by overgrazing and lack of plant food. The Wisconsin Agricultural Experiment Station has secured excellent results by disking, liming, phosphating, and reseeding such areas with alfalfa, sweetclover, and some grasses. Under ordinary conditions, however, where a fair stand of desirable grasses is present and white grubs are not injurious, only fertilizing and proper grazing management are necessary to produce a heavy erosion-resistant turf.

In semiarid regions, deferred grazing combined with proper management and, under some conditions, mowing for weed control, will bring

grasslands back to former productivity without reseeding. The use of contour furrows on such land is, however, generally advisable.

Plants Used in Erosion-Control Program

There is a large number of interesting and worth-while developments in the use of close-growing vegetation for soil conservation. For example, alfalfa-grass mixtures are used extensively in the soil conservation program on the recommendation of State experiment stations. There are many advantages in the use of such mixtures over alfalfa or grass planted alone. Among these are increased yields, reduction in heaving and subsequent winter-killing of alfalfa, prevention of weed encroachment, elimination of danger of animal

FIGURE 7.—Blue grama (*Bouteloua gracilis*) in the San Antonio, Tex., nursery, seeded in double 8-inch rows spaced 32 inches apart. Seedings were made April 10, 1935. This is the second seed crop being harvested in October; the first heads appeared in July but were blasted by unfavorable weather conditions. The small stripper shown in the picture was developed at the San Antonio nursery and is adjustable as to height.

bloat, and increase in value for erosion control. Kudzu (*Pueraria thunbergiana*), where it is adapted, is proving to be of exceptional value in gully control and for revegetating badly eroded land. It is also an excellent forage plant. Burnet (*Sanguisorbia minor*) is showing excellent possibilities for erosion control and forage uses in the far West. Practically every commercially available grass and legume and many herbs and shrubs have been used on farms in the erosion-control projects. Large quantities of seed of many native grasses not commercially available have also been collected for direct planting on these projects.

A determined effort has been made to develop additional plants, both native and foreign, for use in the program. More than 2,000 lots of seed were obtained in Russian Turkistan, Turkey, and China in 1934, particularly from semiarid regions. In the same year and also in 1935, botanists scoured our western country collecting seed of promising native plants. These were brought together in nurseries at Pullman, Wash., Mandan, N. Dak., Cheyenne, Wyo., Tucson, Ariz., Santa Paula, Calif., San Antonio, Tex. (fig. 7), Stillwater, Okla., and Lincoln, Nebr. Many of them are showing much promise. Table 4 gives a partial list of promising plants.

Table 4.—*Partial list of promising soil conservation plants being developed in nurseries*

Name	Source	Qualities	Adaptation
Agropyron dasystachyum (thickspike wheatgrass).	Native	Erosion-control value fair; somewhat difficult to establish; seed habits good; yields good; palatability excellent; sod-forming and drought-resistant.	Northern Great Plains and intermountain region; southern limit of adaptation unknown.
A. elongatum	Union of Soviet Socialist Republics.	Conservation value good; ground cover good; very easy to establish; fairly good seed habits; yield fair; palatability fair; drought-resistant; late maturing; large seed.	Same as *A. dasystachyum*.
A. inerme (beardless wheatgrass).	Native	Similar to *A. elongatum*	Do.
A. pungens	Europe	Forms good ground cover; good soil binder; easy to establish; good seed habits; good yields and excellent palatability; sod-former.	Do.
A. sibericum	Union of Soviet Socialist Republics.	Conservation value good; easy to establish on eroded and steep land; ground cover fair; seed habits good; yields fair; palatability fair; reseeding habits good; drought-resistant; good spring and fall recovery.	Do.
A. smithii (western wheatgrass—bluestem).	Native	Fairly easily established on eroded and steep land; does not do well on poor, thin, or sandy soils; ground cover good; seed habits fair; yields good; palatability excellent; reseeding habits fair.	Entire western United States.
A. spicatum (bluebunch wheatgrass).	do	Hardy, drought-resistant; good soil binder; easy to establish; good seed habits; palatable; yields good.	Pacific Northwest and northern intermountain region; southern limit of adaptation unknown.
Andropogon furcatus (big bluestem).	do	Highly palatable; produces seed in profusion; prefers deep soils with more than average moisture, where it forms dense sod; on hillsides and thinner soil, it has a bunchy habit of growth.	Eastern Great Plains from Canada to southern Texas; has possibilities in other regions.
A. scoparius (little bluestem).	do	Perennial bunch grass; deep root system; drought-resistant; winter-hardy; good yielder; good seeder; palatable; easily established.	Same as *A. furcatus*
Astragalus mortoni	do	Good soil-binding qualities; forms good ground cover; easily established; seed habits good; palatability questionable; does well on sandy silt loam with 9 inches of rainfall where wind erosion is moderate to severe; spreads by rhizomes; used for hay and feed.	Intermountain region.
Atriplex semibaccata (Australian saltbush).	Australia	Good soil binder; crowds out weeds; good for gully control; forms excellent ground cover; easily established; fleshy fruit relished by birds.	Southern California, Arizona, and New Mexico; northern limit of adaptation unknown.

Table 4.—*Partial list of promising soil conservation plants being developed in nurseries*—Continued

Name	Source	Qualities	Adaptation
Bouteloua gracilis (blue grama).	Native	Perennial bunch grass; very drought-resistant and winter hardy; able to establish itself under arid conditions; high palatability; produces abundant seed of high germination; increases at expense of other grasses under severe grazing.	Primary adaptation throughout western Great Plains; excellent possibilities in other regions of low rainfall.
B. curtipendula (side-oats grama).	do	Perennial, medium-short bunch grass; very drought-resistant and last to disappear under severe overgrazing; poor seed producer; when seed is produced in late summer, yields are higher; strains of late summer blooming varieties are being selected.	Throughout eastern and central Great Plains.
Bromus carinatus (California brome).	do	Spreading rapidly in western Washington; seeds readily on burned areas and on cultivated lands; good conservation value.	Primary adaptation on west coast but found in more or less limited quantity throughout Western States.
B. marginatus	do	Excellent conservation value; easy to establish on eroded and steep lands; ground cover excellent; seed habits good; yields good; palatability good.	Common on the west coast but found in western Texas, Colorado, and South Dakota.
Buchloë dactyloides (buffalo grass).	do	Perennial grass; spreads by numerous stolons; fine leaves and thick sod; very drought-resistant; seeds produced but difficult to harvest; propagated by pieces of sod; palatable even when mature; crowds out taller grasses under severe grazing.	Found on heavy soils throughout western and central Great Plains.
Calamagrostis pseudophragmites.	South Africa	Has become well established on range and produced seed.	Southern intermountain region; general adaptation unknown.
Chloris berroi	do	do	Same as *Calamagrostis pseudophragmites.*
C. gayana (Rhodes grass)	Africa	Tall succulent grass, producing number of leaves and long stolons; used in pasture and as hay crop when temperatures do not fall below 18° F.; heavy yields; produces best on heavy soils; good seed habits; easy to establish.	Texas and adjoining States; general adaptation unknown.
Elymus canadensis (Canada wild-rye).	Native	Hardy, drought-resistant; easily established on eroded lands and steep soils; forms excellent cover; good germination; palatability fair; excellent reseeding habits.	Adapted throughout eastern Great Plains and Corn Belt but found throughout United States except in the Southeast.
E. condensatis (giant wild-rye grass).	do	Has strong perennial roots and develops vigorous green growth with rains; valuable for gully control.	Adapted to intermountain region and Pacific coast.
E. dahuricus	Union of Soviet Socialist Republics.	Ground cover good; easy to establish; seed habits good; yields good; palatability fair.	Northern Great Plains and intermountain region; southern limit of adaptation unknown.
E. glaucus (blue wild-rye).	Native	Similar to above; easier to handle; slightly finer vegetative growth.	Adapted to intermountain region and Pacific coast.
E. juncus	Union of Soviet Socialist Republics.	Ground cover good; easy to establish; seed habits good; yields good; palatability fair.	Adaptation not definitely known but probably northern Great Plains and intermountain region.
E. sibericus	do	do	Adapted to the northern Great Plains and intermountain region.
E. triticoides (beardless wild-rye).	Native	Conservation value excellent; can be established on eroded and steep land; ground cover excellent; fairly easy to establish; seed habits fair; yields good; palatability excellent; sod-forming.	Throughout intermountain region.

Table 4.—*Partial list of promising soil conservation plants being developed in nurseries*—Continued

Name	Source	Qualities	Adaptation
Ephedra sinica (mahuang).	China	Forms dense mat; excellent sand binder; fruit relished by birds.	Grown in Arizona; general adaptation unknown.
E. viridis (Mormon tea).	Native	Excellent sand binder; very hardy and extremely drought-resistant.	Southwest extending into Utah and Nevada.
Eragrostis curvula	South Africa	Bunch grass, producing long leaves and abundant seed which germinate readily; valuable grass for meadows; able to survive on southern range where it spreads by reseeding; probably not winter-hardy in Northern States.	Southern intermountain region; shows promise of adaptation to other regions.
E. lehmanniana	do	Similar to *E. curvula*	Same as *E. curvula*.
Erodium texanum (Texas filaree).	Native	Annual constituent of upland pasture in central and western Texas, where it produces considerable succulent feed during February, March, and April; grows thickly; good normal cover.	Southern Great Plains and intermountain region.
Hilaria belangeri (curly mesquite).	do	Perennial turf-forming grass that spreads by slender arched stolons; great difficulty in securing seed supplies; will tolerate sandy soils; high palatability; high erosion-control value.	Same as *Erodium texanum*.
H. jamesii (galleta grass)	do	Erect, heavy-rooted perennial with coarse rhizome; apparently drought-resistant and easy to establish at San Antonio.	Southern Great Plains and intermountain region.
Hordeum bulbosum	Union of Soviet Socialist Republics.	Conservation value excellent; easy to establish on eroded and steep land; excellent ground cover; reseeds easily; yields good; drought-resistant; broad leaves which remain green after seed matures.	Pacific Coast States; general adaptation unknown.
H. nodosum	Native	Conservation value good on north slopes and gullies; ground cover excellent; very easy to establish; seed habits fair; yields good; reseeding habits fair; palatability fair.	Intermountain region
Hyparrhenia hirta	Introduced	Bunch grass; promising in southwest Texas; grows to height of 4 feet; produces seed throughout the year.	Southern Great Plains; general adaptation unknown.
Lathyrus sylvestris (flat pea).	Native	Perennial forage plant in western Washington, difficult to establish but maintains itself indefinitely; holds leaves well and is high in protein.	Pacific Northwest; general adaptation unknown.
Lippia canescens (lippia).	Europe	Good ground cover; thrives in poor soil; good conservation value; easy to establish; propagates by pieces of sod.	Grown largely in California; general adaptation unknown.
Mesembryanthemum croceum (ice plant).	South Africa	Low-growing, mat-forming perennial; suitable for covering steep banks and poor eroded slopes; propagated by seed or cuttings.	Grown principally in California; probably adapted to the Southern States.
M. roseum (ice plant)	do	do	Do.
Oryzopsis hymenoides I(ndian ricegrass).	Native	Conservation value very good on wind-erosion areas; ground cover fair; ease of establishment fair; seed habits fair; yields fair; palatability fair; reseeding habits good.	Adapted throughout the entire western United States.
Palicum virgatum (swntchgrass).	do	Perennial bunch grass with tough, deep, short rhizome, coarse blades and stems; produces abundant seed which germinates readily; plants resume growth early in March; young seedlings very vigorous; valuable in meadow mixture and in waterways.	Very wide adaptation; best adapted to eastern Great Plains but found from Maine to Florida and west to Arizona and Montana.
Pennesetum clandestinum (kikuyu grass).	South Africa	A low-growing, perennial, dioecious plant; only female plants introduced; produces no seed; has both underground and surface runners; spreads rapidly; is palatable and drought-resistant; produces abundance of green feed or hay.	Grown in southern California, Arizona, and Texas; general adaptation unknown but plants grown in Florida were badly diseased.

Table 4.—*Partial list of promising soil conservation plants being developed in nurseries*—Continued

Name	Source	Qualities	Adaptation
Pentzia incana	do	Valuable as soil binder to check sheet and gully erosion; plants are hardy and extremely drought-resistant, surviving through stress conditions; high forage value.	Southern intermountain region; general adaptation unknown.
Poa ampla (big bluegrass).	Native	Good soil binder, especially in wind-erosion areas; good ground cover; can be established fairly well; grows well in mixture; palatability excellent; good seed habits; yields fair.	Found throughout intermountain region.
P. nevadensis (Nevada bluegrass).	do	Similar to *P. ampla* but more difficult to establish because of small seed and erratic delayed germination.	Adapted to northern intermountain region; southern adaptation unknown.
Sanguisorbia minor (burnet).	Europe	Good under semiarid conditions; good forage; excellent erosion control; good seeding habits.	Grown on the Pacific coast but general adaptation unknown.

STRIP CROPPING, with alternate strips of tilled and untilled crops, is coming into wider use as a practical method o erosion control on sloping lands. Usually it is done on the contour, but this may be modified to suit conditions. This article shows the beneficial results of the practice, gives directions for laying out the strips, and touches on the place of strip cropping in the farm rotation.

Strip Cropping

By WALTER V. KELL [1]

ACCORDING to estimates made by the Soil Conservation Service in each of the States and checked by State colleges, experiment stations, and other agencies in the States working on the land-use problem, about 61 percent, or 252,363,100 acres, of the cultivated land of the United States is sufficiently rolling to cause run-off of rain water and erosion when not protected by vegetation.

Strip cropping is one of the practices recommended for erosion control and soil conservation that has a wide potential application on this area. Every farmer producing diversified crops has the choice of growing these crops in blocks in large fields or of dividing the fields into relatively narrow strips so that each clean-tilled strip will be protected by a noncultivated strip of small grain, hay, or grass.

The reason for this practice is obvious. When large fields or blocks of sloping land are plowed and cultivated at one time, as has been common practice in the past, they are subjected to maximum erosion for long periods until vegetation is reestablished. In contrast to this wasteful practice, large fields and long slopes can be protected against erosion by plowing and cultivating alternate strips, always leaving protection strips of erosion-resistant crops between the clean-tilled areas. The strips can be farmed in rotation and in combination with other soil conservation practices where necessary, just as fields can be.

There are three types of strip cropping commonly used in the United States—contour strip cropping, field strip cropping, and wind strip cropping.

CONTOUR STRIP CROPPING

Contour strip cropping is the production of the ordinary farm crops in long, relatively narrow strips of variable width, on which dense ero-

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sion-control crops alternate with clean-tilled or erosion-permitting crops (fig. 1), placed crosswise of the line of slope, approximately on the contour. While it is desirable to follow the true contour, it is not always possible to have parallel strips with all the rows of a given strip exactly on the level, because of variations in the slope of the land. It has been found in practice that if the soil is fairly permeable and the rows deviate from the contour only slightly, usually not over 2 percent, and then for only 100 feet or less, this deviation will cause no serious erosion.

FIELD STRIP CROPPING

Where the soil is absorbent and where it would be impracticable to follow the true contour, a modified form of contour strip cropping is

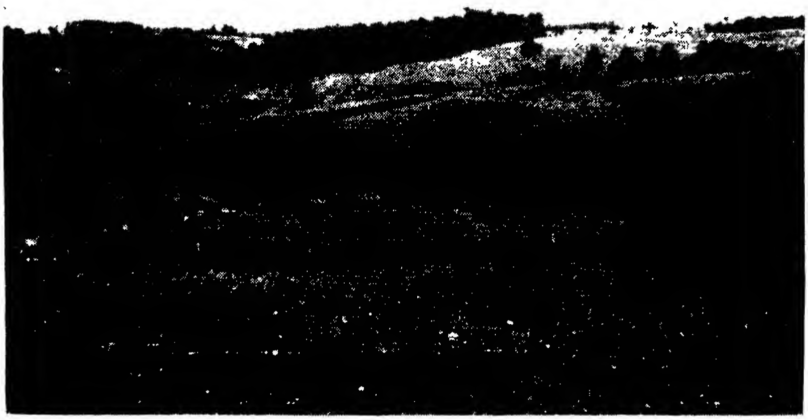

FIGURE 1.—Contour strips of corn alternating with close-growing vegetation reduce run-off and prevent accelerated erosion.

sometimes employed on uniform slopes or on land that is undulating with no definitely defined slopes. This is referred to as field strip cropping.

Field strip cropping is the production of the regular farm crops in more or less uniform parallel strips (fig. 2), laid out crosswise of the general slope, but not parallel to the true contour. Field strip cropping, unless applied to very regular slopes, is a poor substitute for contour strip cropping, but it is usually a step in the right direction and is far superior to exposing to erosion at one time entire fields with long slopes. If these straight strips cross low areas or natural depressions the rows of cultivated crops thus thrown off the contour will accumulate run-off that will cause erosion unless the waterway is protected with permanent vegetation. Waterways in grass or other vege-

tation (fig. 3) increase the effectiveness of field strip cropping and permit its application to larger areas.

WIND STRIP CROPPING

Wind strip cropping is the production of the regular farm crops in long, relatively narrow, straight, parallel strips placed crosswise of the prevailing wind without regard to the contour of the land. Wind strip cropping, which is applicable to limited areas, may be slightly more effective in retarding wind erosion than contour strip cropping, but usually has little value in conserving water. For this reason, the advantages of each type should be carefully weighed. The increased vegetative growth resulting from the moisture saved with

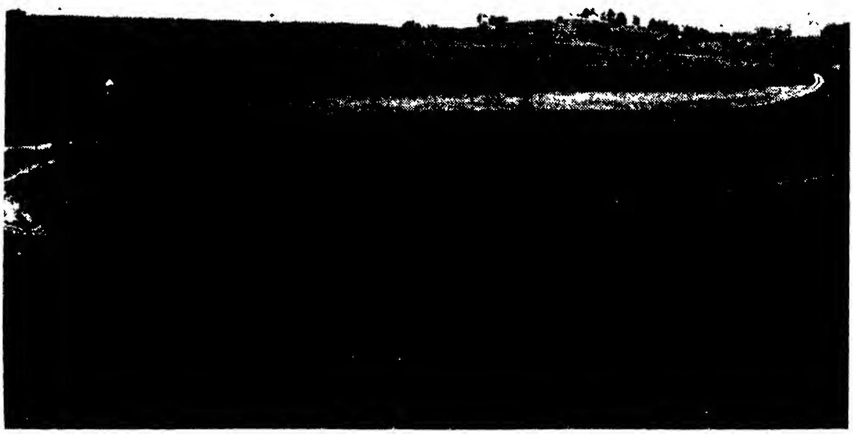

Figure 2.—Field strip cropping. Strips laid out parallel, of uniform width, and crosswise of the slope can be used to advantage on uniform slopes.

contour strips may make them more desirable than strips designed to resist only wind.

STRIP CROPPING A FORM OF VEGETATIVE CONTROL

Strip cropping, regardless of the type, is purely a vegetative control of water, wind, and soil, and its effectiveness is dependent on the production of an adequate cover of the right kind of vegetation to offer resistance to wind or water. No better measures to control erosion have been devised by man than those found under natural conditions. Among these natural measures, grass is probably the most effective. Lands covered by a natural, heavy sod of grass suffer no serious run-off or loss of valuable topsoils in seasons of normal rainfall.

It is now definitely known that, other things being equal, the longer the slope or the larger the area from which water accumulates, the greater the danger of erosion. The average farm should have, in combination with other soil-conserving devices, a sufficient acreage of erosion-resistant and soil-building crops, sown in long strips, to break up large fields and at all times protect the clean-tilled areas.

Not all of the close-growing, erosion-resistant farm crops are as efficient as grass, but the small grains and most of the legumes and other hay crops are good substitutes and usually can be utilized effectively. Advantage should be taken of the erosion-resistant crops best adapted to the locality when planning a strip-cropping system.

FIGURE 3.--Rearrangement of fields by removing fences often makes it possible to have long level rows of cultivated crops, which can be produced much more economically than short rows. Note the two natural waterways in the foreground protected by permanent grass.

Observations made on nearly a million acres of land strip cropped under various conditions indicate that the practice when properly planned is very effective in conserving soil and water.

Limited experiments with strip cropping conducted by some of the Soil Conservation Service experiment stations tend to substantiate these conclusions. At the Temple, Tex., station (table 1), it was found that for the period 1932–36 the plot that was strip cropped lost less than 1 percent of the rain as run-off and less than 4 tons of soil per acre, as against nearly 7 percent of the total rain and about 39 tons of soil per acre for cotton planted on the contour; and almost

16 percent of the rainfall and more than 89 tons of soil for cotton rows up and down the hill. Sixteen times more water and soil were lost under rows up and down the slope than under strip cropping.

Table 1.—*Water and soil losses under strip cropping and other methods of cultivation of cotton on black Houston clay, Temple, Tex., 1932–36* [1]

Cropping condition	Plot size		Water loss		Soil loss per acre
	Area	Length	Depth	Percentage of rainfall	
	Acre	*Feet*	*Inches*	*Percent*	*Tons*
Strip cropping cotton and control crop [2]	0.0463	168	1.546	0.95	3.362
Cotton on contour	.0847	168	11.048	6.81	38.96
Cotton, rows down slope	.0309	168	25.364	15.63	89.07

[1] Average annual rainfall, 34.78 inches; average slope, 3½ percent.
[2] 24-foot strips Nos. 1 and 4 control; rotation, redtop cane, Sudan grass, oats, and vetch. Strips Nos. 2, 3, 5, and 6, cotton planted on contour.

The run-off and soil loss resulting from one rain of almost 5 inches that occurred at this same station on July 4 and 5, 1936, are given in table 2. During this rain the strip-cropped plots lost only 5.4 percent of the water and 269 pounds of soil per acre, while the plots with rows of cotton up and down the hill lost 64.2 percent of the water and 33,032 pounds of soil per acre.

Table 2.—*Water and soil losses under strip cropping and other methods of cultivation of cotton on black Houston clay, 3½-percent slope, Temple, Tex., after a storm, July 4 and 5, 1936* [1]

Plot No.	Cropping condition	Length of plot	Water loss		Soil loss per acre	Crop residue
			Depth	Percentage of rainfall		
		Feet	*Acre-inches*	*Percent*	*Pounds*	
12	Strip cropping—contour cotton and redtop cane	168	0.269	5.4	269	Vetch.
13	Cotton on contour	168	2.481	49.8	23,905	None.
14	Cotton, rows down	168	3.199	64.2	33,032	Do.
15	Strip cropping—contour cotton and oat stubble	168	1.175	23.6	.992	Sudan grass stubble.
16	Strip cropping—contour cotton and Sudan grass	168	.718	14.42	307	Vetch.

[1] Total rainfall, 4.98 inches; maximum intensity, 1.20 inches per hour for a 5-minute period; 0.16 inch for 1 hour.

At Guthrie, Okla., on Vernon fine sandy loam soil with a 3- to 4.5-percent slope, similar results were obtained by the Soil Conservation Experiment Station, although they were not quite so extreme. For the period from March 1934 to December 1936, strip-cropped plots lost much less soil than continuous cotton planted on the contour. The data are shown in table 3.

Table 3.—*Water and soil losses under strip cropping and other methods of cultivation of cotton on Vernon fine sandy loam, Guthrie, Okla., March 1934 to December 1936* [1]

Plot No.	Cropping condition[2]	Slope	Water loss: Depth	Water loss: Percentage of rainfall	Soil loss per acre
		Percent	*Acre-inches*	*Percent*	*Tons*
1	Cotton on contour, alfalfa control strip	4.50	4.117	4.69	1.459
2	Cotton on contour, alfalfa and Sudan grass control strip	4.00	11.527	13.47	4.762
3	Continuous cotton on contour	3.50	9.778	11.96	8.265
4	42 feet oats-Sudan grass control, 63 feet cotton on contour	3.00	9.717	11.09	4.901

[1] Total rainfall, 83.61 inches; size of plots, 1 acre—128 by 340.3 feet.

[2] All cotton followed by a wheat cover crop. Plot 1, 12 rows of cotton to 1 strip and slightly narrower control strips. Plot 2, 12 rows of cotton to 1 strip and slightly wider control strips.

While experimental results are not yet available for all types of soil, degrees of slope, and combinations of crops, indications are that on fertile ungullied soil contour strip cropping can be used effectively on practically all sloping land devoted to the production of clean-tilled crops.

ADVANTAGES OF STRIP CROPPING

Strip cropping, combined with contour tillage, crop rotations, winter cover crops, diversion ditches, and terracing where necessary, has been proved by both experiment stations and demonstration farmers to be very economical and effective and one of the most practical means of conserving soil and water on cultivated land.

Contour strip cropping divides the length of the slope, checks the momentum of run-off water, filters out the soil being carried off, and increases the absorption of rain water by the soil. This is accomplished by the multitude of obstructions offered by the dense, close-growing crops in alternate strips, which by slowing down the rapid flow of water cause it to spread and soak into the soil.

Root growth and earthworms open pores or tiny tunnels in the soil and the dense vegetation on the control strips prevents them from being sealed by silt. This condition permits greater absorption of water by the soil. The filtering action of the control strips is very important, as muddy water laden with sand and silt is more erosive than clear water because of its higher specific gravity and because the sand and other soil particles moved by the water produce an abrasive action.

Strip cropping by providing a larger number of small fields encourages the use of a proper crop rotation and helps maintain a balance of soil-building and harvested crops. It can be installed at practically no expense and the cost of maintenance is very low. The strips do not require the same degree of engineering exactness and accuracy in their installation as do terraces, because a slight error can easily be corrected the next time the strip is plowed.

Strip cropping with rows on the contour not only conserves soil and water but also time and energy. Less time is required to cultivate

a given area in long rows than in short rows because of the fewer turns, and contour rows can usually be made longer than rows in the square fenced field. Often two or more fields can be thrown together, thus making longer rows and sometimes saving fence. In tractor operations on the contour, time is saved by not having to stop to change gears in going up and down hill. By keeping the strips and rows on the level, less power is required, an important item on some farms.

Reducing the run-off by strip cropping prevents the loss of plant food applied in the form of fertilizer, manure, or crop residue, and is thus reflected in crop yields (fig. 4).

Strip cropping, in conjunction with contour tillage and terraces (fig. 5), increases the efficiency and safety of the terrace system by

Figure 4.—Crops grown in contour strips make good use of the extra moisture and plant food that is trapped and prevented from clogging the drainage channels.

being a secondary defense in emergencies and by helping to prevent overtopping, channel silting, or ridge washing. It also facilitates terrace maintenance by distributing the farmer's work over the farm so that he can frequently observe and repair any defects before they become large and destructive. Much of the destroyed and abandoned land is the result of failure to observe and promptly repair the apparently harmless little rill or finger gully.

While strip cropping alone will not completely control erosion on all soils and slopes, it has so many advantages over the old system of plowing, cultivating, and otherwise subjecting the entire areas of large fields to erosion and consequent loss of soil and water, that it merits careful consideration and adoption by every crop farmer operat-

ing land subject to erosion who is interested in improving or maintaining the permanent productiveness of his farm.

LAYING OUT STRIPS

It is difficult to state rules that will apply to all conditions in planning and laying out a strip-cropping system. A few fundamental suggestions, however, are applicable to any condition. In the first place, one must have the courage to rearrange his farm completely if need be. This may mean relocating fences to change the field arrangement, taking some steeper slopes out of cultivation and retiring them to pasture or trees, taking some level pasture lands that are suitable for cultivation out of pasture, and adjusting rotations to meet the variations in erodibility of the soil. Practical, sound soil conservation must be the first consideration, and it may therefore be necessary on

FIGURE 5.—Terraces and contour tillage are strong allies of strip cropping in preventing erosion and conserving moisture.

some farms to change the farming system or land use to fit these soil-conserving methods.

In laying out a strip-cropping system one should first consider the approximate difficulty with which erosion can be controlled in order to determine intelligently the width and location of the strips. This requires careful consideration of existing conditions, such as variations in relief that will determine whether or not the strips can be uniform in width with parallel boundaries or vary in width with irregular boundaries; points where run-off concentrates, so that provision can be made for safely conducting accumulated water off the field; amount and distribution of run-off water flowing across this field from the drainage area above; length of slope on which run-off can accumulate; present moisture-retaining condition of the soil; soil type, such as

sandy loam or clay; crops used in the rotation that will provide both clean-tilled and dense-growing vegetation; and the type of machinery used in the production of these crops.

While no specific rules can be given for laying out a strip-cropping system that will apply to every farm, a general knowledge of the function of the strips in breaking up the length of erodible slopes or clean-tilled areas will usually suffice. Long, steep, impervious slopes will naturally require a much larger proportion of close-growing,

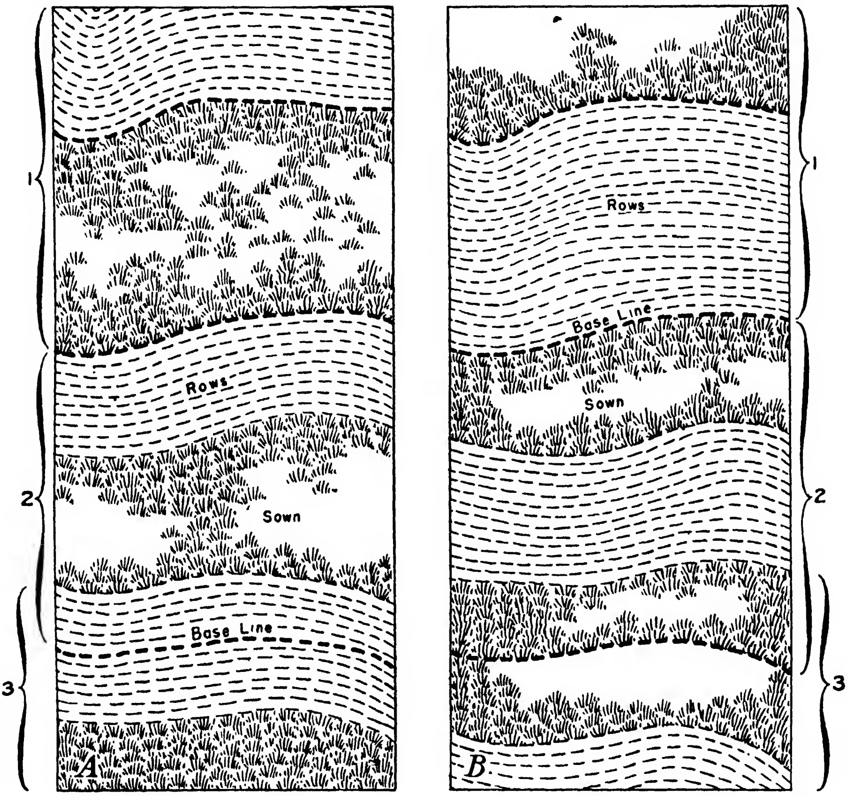

Figure 6.—Three methods of using the base line in laying out strip crops. The strips may be measured either (1) above or (2) below the base line, or they may straddle it (3). This diagram also illustrates how crops can be rotated in a strip-cropping system. Row crop areas will be seeded one year to close-growing crops (*A*), and the next year these strips may be plowed for row crops (*B*).

erosion-resistant crops than short, gentle, pervious slopes. This condition will vary under field conditions from slopes that are so difficult to control that row crops are never justified, to slopes that can be safely farmed in fairly wide strips of row crops alternating with equally wide or narrower strips of close-growing crops. If a soils map of the farm is available, it is worth while to study the soil type, degree or amount of erosion that has already taken place on that field, percentage of slope, drainageways, and land cover, before laying

out the strips. This information should be very helpful in establishing a base line or starting point for the first strip to be laid out.

The base line may be established by various methods but must be on the true contour and so located that as many strips as possible may be measured from it both up and down the slope. On irregular slopes the base lines will need to be closer together than on regular slopes. There are three ways of using the base line (fig. 6). It may form either the top or the bottom boundary of the strip, or it may be used for the center line.

The boundaries of the strip may be measured from the base line with a tape measure carried by two men, one walking on the base line and the other at the desired distance from the base at the other end of the tight tapeline, which must be carried at right angles to the base. Stakes can be set 50 or 100 feet apart by the man who is staking the strip boundary. Immediately after the boundaries have been staked they should be more permanently established by plowing a light furrow.

Any comparatively accurate method may be used in establishing base or contour lines, but the eye alone is not sufficiently accurate. For ordinary slopes any of the simple levels such as the Abney, Locke, line level, or common level will be satisfactory. On long, relatively uniform contours, a tripod level is advantageous because the greater range of the telescope will save time. Strips should be laid out when the work will least interfere with growing crops. It may not be possible to bring an entire farm under a strip-cropping plan the first year, on account of disrupting the rotation, but usually 2 or 3 years is sufficient time in which to bring every cultivated field into the system.

After establishing the base or contour line the next problem is to determine the width of the strips. Usually, as previously stated, the longer the slope the greater the erosion, but in the effort to break the length of slope by strip cropping, strips should not be so narrow as to be impractical. In general the width of the strips will depend on several factors, including type of soil, percentage of slope, length of slope, amount of normal rainfall, kind of crops, rotation, use of cover crops, amount of soil humus, degree of erosion, and, to some extent, type of farming followed. The relation of these factors to strip cropping has previously been discussed. As a very general guide, strips under the most favorable conditions should rarely, if ever, be more than 200 feet in width and in order to be practical should seldom be less than 50 feet in width. The kind, amount, and density of the vegetation used in the control strips is another factor in determining width. On soils of low fertility that will produce only scant vegetation, or where gullies have started to form, control strips will not be so effective and should in such cases be reinforced with terraces. Too much should not be expected of strip cropping in its early stages until the strips become well established and the soil fertility has been improved so that thrifty, dense vegetation can be produced.

In order to see this practice in the field, it is suggested that farmers interested in laying out a strip-cropping system for their own farm visit one of the Soil Conservation Service demonstration areas. Almost 1,000,000 acres have been laid out by the Service in strips of

various widths and on all kinds of soils and slopes. A solution to many problems may be found on these areas.

Laying out a strip-cropping system on terraced land is relatively simple because the contours are permanently marked by the terraces and the width of the strips can be adjusted to the terrace interval. There are several methods of locating the strips on terraced fields. They can be placed on the terrace interval, from terrace ridge to terrace ridge, or they can straddle the terraces, with modifications to suit the conditions. Strips astride the terrace divide the terrace interval and are more effective in reducing erosion. They also facilitate terrace maintenance and admit of the maximum number of full-length parallel rows. Where terraces are not parallel, the irregular areas can be occupied by close-growing, noncultivated crops.

Border strips or turn strips are often utilized to advantage in producing hay and as an aid in the cultivation or harvesting of other crops. They also serve as roadways connecting the various strips so that each strip is easily accessible for the different tillage and harvesting operations. Irregularities of slope or relief make it impossible to have all strips parallel and of uniform width; therefore, provision should be made to reach each area without driving through unharvested crops or up and down the slope over unprotected land. Border strips make this possible.

Irregularities of relief also make it impossible to have all rows laid off parallel to the established base line or terrace strictly on the true contour. This makes it necessary either to have point rows or to keep the rows parallel and permit some deviation from the contour. The amount of deviation from the true contour that can be permitted will depend on the type of soil and a number of other factors, but field trial will be the best guide, and if it is found that some rows have too much slope and are causing erosion, the error can be corrected the next time the strip is planted to row crops. Generally, under favorable conditions, this deviation from the true contour should not exceed 2 percent (2 feet of fall in 100 feet of horizontal distance), and then for only short distances. If strips cannot be laid out sufficiently straight to be practical without deviating 2 percent or more from the true contour, then the low areas where water accumulates should be protected by establishing permanent grassed waterways. These are discussed in the article, Mechanical Measures of Erosion Control. After several years' farming, the sediment collected by the vegetation in the waterways may fill them sufficiently to reestablish the true contour.

STRIP CROPPING AND ROTATION

Producing the ordinary farm crops in long, level strips instead of in large fields that necessitate operating up and down hill is one of the simple, easily adopted, yet very effective soil- and moisture-conservation measures. It should be combined with other good farming practices so that the soil can be permanently maintained in a highly productive state. The soil should be occupied either by a crop for harvest or by a protective cover crop to be returned to enrich the soil. Crops should be rotated in the strip system, as well as in the old large-field system.

In planning the rotation, there may be some critical slopes that cannot adequately be protected with the ordinary annually rotated crops. These should be taken out of the regular rotation and protected by seeding to perennial vegetation, such as alfalfa-grass mixtures, kudzu, or perennial lespedeza, that will give permanent protection to both the critical slope and the areas above and below the slope. These perennial strips can be a part of the strip-cropping system even though they may not be a part of the regular rotation. The need for this special protection is evident all over the country. When the fields are bare and thin, light-colored areas where the productive topsoil has been washed off can be seen in many fields; and when covered by crops, sickly green, scant vegetation marks the spot.

Good rich soils produce profitable crops, while thin, eroded soils produce unprofitable crops. Strip cropping, if employed on the sloping agricultural areas of the United States, will help keep the soil permanently productive and profitable.

ALTHOUGH control of erosion by mechanical means usually involves a certain amount of preliminary technical calculation if it is to be effective, the measures actually employed can be put into effect by farmers. This article tells what these measures are. First it describes methods that may be applied to cultivated land—ditches for the interception of water, absorption and drainage terraces, basin listing, contour furrowing, bench terraces, and special measures for irrigated land. Measures adaptable to pasture and range land are considered next. The building of channels adequate to carry run-off is then dealt with, followed by a discussion of the control of destructive gullies. The article concludes with an account of the mechanical measures that may be used to reduce wind erosion.

Mechanical Measures of Erosion Control

By M. L. Nichols *and* T. B. Chambers [1]

ALL MEASURES of erosion control in the last analysis are mechanical in action. Frequently, however, artificial structures such as dams, terraces, and diversion ditches, as well as certain field practices, such as contouring, ridging, subsoiling, etc., are classified as mechanical measures of control to distinguish them from vegetative controls. In general, these so-called mechanical measures are most practical and economical when used to supplement vegetative controls and where their construction and maintenance may be interwoven with good field cultural practices. Water concentrated on steep slopes may have great erosive force, however, and an understanding of the principles of hydraulics is necessary for their practical application.

When rain falls upon the soil, a series of effects is started the integral parts of which, considered by themselves, may be small, but which in the aggregate represent forces of great magnitude. The impact of the raindrops themselves represents a considerable force beating upon the soil. This force usually may be counteracted by vegetative covering. Where vegetation does not exist, another series of physicochemical forces is brought into effect by the action of the water on dry lumps of soil. Part of the water that falls upon the soil is drawn into the fine spaces or capillaries. Air is trapped and compressed, the material that causes the soil to cohere in lumps is softened, and the lump breaks down in a series of small "explosions." Soil material is dispersed and scattered in a form easily moved by surface water.

The unabsorbed water then collects into small pools, and with

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increasing accumulation overflows the depressions under the action of gravity to form rivulets and rills, moving the loosened soil with it. Some of the soil particles provide abrasive material, which cuts out channels, forming washes of varying proportions; other particles are carried into the soil pores, partially or entirely clogging them and thus preventing absorption and increasing run-off.

The amount of energy involved in all this may be realized when it is considered that 1 inch of rain from 1 acre running down a hill 50 feet high dissipates over 11,000,000 foot-pounds of energy. The force at any point depends upon the concentration and velocity of the water. This total energy, of course, is small compared with the total energy of impact and the total of the physicochemical forces involved in the wetting of dry soil.

From these simple facts it may be readily seen that the fundamental principles of control necessitate practices that assist in—

(1) Surface protection by vegetative covering.
(2) Absorption of the maximum quantity of water.
(3) The movement of large concentrations of water from steep areas through protected channels.

In general, vegetation furnishes the best surface protection. This has been dealt with in other articles in this Yearbook and need only be mentioned here. However, in cultivated areas this protection is impossible except insofar as proper rotations are followed. When, in a rotation, considerable quantities of organic matter are plowed under, this residue furnishes cementing material and food for numerous molds that tie the soil together with their numberless mycelia. This effect is apparent for a considerable period of time.

Experiments show that various structures, both clods and surface shapes such as are produced by contour furrowing and listing, and such practices as deep tillage, subsoiling, mole drainage, or subsurface tillage, have appreciable effects on the surface movement of water. Any practice that increases the total absorption, such as basin listing, decreases the quantity of run-off to be handled mechanically.

The most common means of preventing large concentrations of water is the use of low-velocity channels or obstructions built across the slopes, which are thus cut into short sections. Mound- or channel-type terraces or hillside ditches are commonly used for this purpose. In general, these provide for the flow of excess water through broad, shallow channels, which offer considerable frictional resistance so that the flowing water has low velocity and little or no erosive power.

The idea that the construction or development and the maintenance of these mechanical features must be a part of regular farming practice is gradually gaining ground, and adaptable practices are being incorporated into regular soil-management programs. The development of mechanical erosion-control measures, the determination of the quantities of water that can be most practically handled by one outlet channel, the dissipation of the energy generated by flowing water on steep slopes and erodible soils with reasonable economy—these involve many technical problems, which can be solved only by trained specialists. Almost invariably, however, the solution resolves itself into a simple, common-sense farm practice, which generally may be applied by the average farm operator with a little guidance from the technician

in estimating the quantities of water to be handled and the forces involved.

CONTROL IN CULTIVATED FIELDS

In considering an erosion-control plan, attention is first given to proper management of the cultivated vegetal cover to simulate natural conditions as nearly as possible. In addition, mechanical measures must often be used in a supplementary or complementary manner, in order to reduce erosion to a point where losses are practically equaled by soil "building" practices. While mechanical measures will ordinarily be beneficial throughout all seasons and are indispensable under some cropping practices, particularly where there are clean-cultivated row crops, they are most necessary and most effective where there is no protective cover, as during the dormant season, at the time of seedbed preparation, or immediately after a crop is harvested.

The season of cultural operations may greatly affect the efficiency of erosion-control practices under any plan of conservation. Plowing for seedbed preparation that destroys surface cover or stubble from preceding crops should not be done further in advance of planting time than is necessary to produce a satisfactory seedbed. Likewise, seeding, plowing under cover crops, and harvesting annual crops should be so managed that the land surface will be exposed for the shortest possible time.

Tillage methods and the action of some tillage implements may render certain soils more susceptible to erosion. Machines that pulverize the soil into a fine dust mulch should not be used except where absolutely essential to the production of a crop. All tillage should be along the contour of slopes in order that furrows or marks left by the machines may act as detention dams for the storage and increased absorption of water.

Mechanical methods of control must be correlated with available farm power and the general crop-rotation system. The importance of mechanical measures is often proportionate to the length of time row crops are used or unprotected conditions exist in the rotation cycle. As an example, a 5-year rotation of corn, corn, wheat, oats, and sweetclover might be assumed under many conditions to offer complete protection for 3 of the 5 years, while a 3-year corn-cotton-tobacco rotation would offer none. Mechanical measures would be relatively more important under the latter rotation, other conditions being the same.

INTERCEPTION

Interception and diversion ditches to conduct water away from cultivated fields are practical on steep or unusually long slopes (fig. 1). The diversion channels are placed above unprotected fields to intercept headwaters from higher slopes, or at intervals across the fields to prevent concentration on the lower portions.

The use of diversion channels is dependent on locations affording suitable places for outlets, as water discharged from the channels into unsuitable outlets may do more damage than if allowed to flow across the slope. Broad, flat channels are constructed to reduce velocity and facilitate crossing with farm implements. The gradient of the channels should be such that nonerosive velocities are maintained under

maximum flow conditions, and the capacity should be sufficient to accommodate the run-off from the heaviest rains to be expected under normal conditions. To avoid blocking of the diversion channels by deposition of eroded material from the area above, it is desirable that each channel be located immediately below a well-vegetated area. The upper channel should be at the lower edge of a pasture, meadow, or woodland, while successive channels down the slope must have permanent buffer strips of close-growing vegetation immediately above them.

TERRACING

The basic function of a terrace [2] is interception of water, which is either absorbed or conducted slowly from the field, depending on

FIGURE 1.—A well-constructed diversion channel with protective strip of vegetation above.

the particular requirements of the locality. The terrace and diversion ditch may be identical in function, but the principles of construction and use are different. The terrace most commonly used is of a standard size and shape, regularly spaced, and of a cross section permitting cultivation over the entire surface. In addition, the terrace may also serve as a guide to contouring when listing, laying out row crops, or performing other tillage operations.

There are two different types of terraces—the absorption type and

[2] The term "terrace" as used in this article refers to the agricultural terrace, which is an earth ridge with channel above placed approximately on the contour of a slope. A "drainage-type terrace," often called simply a terrace, is constructed with a slight gradient toward one end. It is used in the humid parts of the country for the purpose of intercepting and diverting water away from cultivated slopes. A "level terrace" is constructed through points of the same elevation for the purpose of impounding water above the terrace ridge. The impounded water is absorbed on the field. This type of terrace is ordinarily used in semiarid sections where dry farming is practiced. A "bench terrace" is the true terrace defined by Webster as "a raised level space, bench, or platform of earth."

the drainage type. The absorption terrace is a ridge with little or no grade designed to hold a large part of the water in the field until absorbed. This is constructed by moving earth from both sides to form a ridge well above the elevation of the slope surface. The drainage-type terrace consists primarily of a channel, the earth from which is moved downhill to form a low flat ridge. The grade of this drainage channel is variable, being level or nearly level at the upper end and increasing little by little along the length of the terrace to afford increased capacity without change in width. The grade and shape of the channel are proportióned so as not to produce an erosive velocity. As a matter of fact, the velocity should be low enough to allow deposition of soil material washed from the interval above (fig. 2).

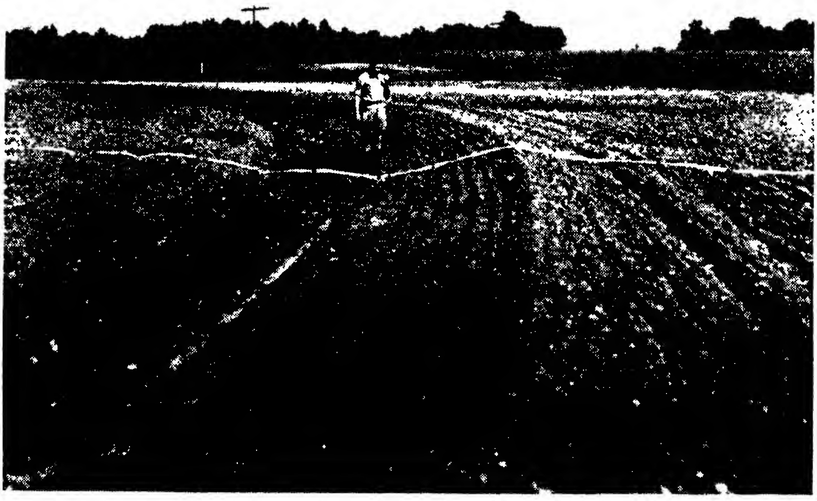

FIGURE 2.—Typical drainage-type terrace.

The cross section of the completed terrace must be such that available tillage equipment is readily adaptable to working on the side slopes of both ridge and channel. The capacity of a drainage terrace must be ample to conduct safely from the field the maximum run-off from a rainfall of the maximum intensity to be expected during a 10-year period or less; likewise, the impounding capacity of a level terrace (i. e., one having no slope or grade in the channel) should accommodate run-off from a rainfall of the same intensity. Rains of higher intensity may occasionally cause considerable damage to a new terrace system, but the cost of construction prohibits the building of all terraces to large enough dimensions to take care of any possible rain.

A wide variety of machinery is adaptable to terrace construction, including the turning plow, disk plow, blade grader, V-drag, and other machines. Within the last few years, the blade grader has been notably improved for terracing purposes by adaptation to heavy tractors and other modifications of design. Two other machines have been developed, the rotary-type pulverizing plow and the elevating grader. These have proved practical in constructing ridge-type terraces under favorable conditions. Under some conditions anyone can use the plow, disk, and small blades to construct satisfactory terraces with farm power, but the process is laborious and few good terraces have resulted from the use of this equipment on the heavier soils. The larger, power-operated, reversible-blade machine is generally the most economical for constructing channel-type terraces. The formation of cooperative associations in several States to purchase this equipment and rent it to farmers has resulted in demonstrating a method of building good terraces at reasonable cost.

While the spacing or location of terraces on the field surface is one of the most important considerations in designing an effective and practical system, very little research data has been developed on this point. The spacings most often recommended at present are largely the result of experience. Numerous terrace systems have been studied, and engineers have used the average spacings of those giving the most satisfactory results as a basis for spacing tables.

The spacing unit most often used is the vertical interval, that is, the difference in elevation of a point on one terrace to a corresponding point on the next. The interval varies with different slope gradients, being greater on the steeper slopes. The increase is not as great as the increase in slope, however, and on flatter slopes the horizontal distance between terraces will therefore be greater than it would be on steeper slopes. Numerous factors such as slope, farming practice, and soil characteristics influence spacing, but the limiting factors are channel capacity, erosion between terraces, and interference with tillage operations.

Terraces may be spaced close together on steep slopes to prevent concentration of water washing rills between them, even though they may have capacity for a wider spacing. Interference with tillage operations, which is aggravated by close spacing, encourages wider spacing. In considering these factors it frequently becomes necessary for financial reasons to compromise on spacing or dimensions of mound or channel which govern capacity. Usually, spacing and dimensions are used that will give reasonable immediate security, and plans are made to develop the structures to larger and safer dimensions as a part of the regular farming operations.

Soil characteristics undoubtedly influence the amount of erosion between terraces more than any other factor under the same conditions of rainfall and cover. The absorptive characteristics of a soil will, of course, affect the total amount of run-off and erosion. It seems a reasonable assumption that terraces should have wider spacing on the more absorptive soils, but results from field experience indicate it is not always tenable. Soils with high absorptive characteristics may have physical qualities that make them unsuitable for retaining large quantities of water behind the terrace ridge. Under

these conditions, closer spacings with smaller terraces seem necessary.

While cropping practices and the types of vegetation to be grown will influence spacings, the decision to increase terrace intervals because an erosion-resisting crop is being used should be made with caution. Economic or other conditions may cause a later change in cropping plans that will produce excessive erosion on the wider intervals. Once the terraces are built it is not feasible to change them to conform with changed cropping plans. They should be constructed initially with a spacing that will make the terrace reasonably safe, even under the more adverse cycle of a different cropping plan.

Terracing must be correlated with land-use practices, and future uses of the land should be considered. Land to be retired to pasture or other close-growing crops will seldom require the additional protection of mechanical control. Only where the soil has been damaged by erosion to such an extent that it will not support a protective vegetal cover, or on exceptionally erodible soils that require mechanical protection during the interim necessary to produce a cover, will such measures be necessary. Under the latter conditions a smaller terrace cross section than would be used on cultivated fields is generally sufficient.

Population density and economic conditions will sometimes dictate land-use practices and produce situations where cultivation is necessary on severely eroded land that should normally be retired, or on slopes too steep for safe tillage. In these situations, construction of terraces may be necessary even though the cost will be high and their effectiveness will be impaired.

The cost of terracing increases with the degree of erosion of the land. In other words, it costs more to protect the less valuable lands. This indicates that terraces should be constructed as soon as possible after a field is placed in cultivation. The virgin conditions of the soil may successfully withstand erosion forces for the time being, but continued unfavorable cropping practices will alter these characteristics so as to permit cumulative rates of erosion in the future.

Maintenance is necessary if the terrace system is to continue functioning properly. Depositions of eroded material in the terrace channel raise the flow line and decrease capacity while tillage will wear down the ridge to some extent. Settlement after construction reduces capacity until the terrace may not be able to handle the water of heavy rains. When the low places and breaks have been properly repaired the terrace can be successfully maintained by the regular plowing operations. A disk or turning plow is entirely satisfactory if used so as to throw earth to the ridge on the absorptive terrace and to increase the size of the channel on the drainage type.

When maintaining the channel the first plow furrow is started at the outside and turned uphill leaving the water furrow, or joining cuts of the plow, at the channel flow line. One or two plowings in this manner will keep the channel clear and if necessary increase its size by widening and deepening (fig. 3). In maintaining the ridge or absorptive-type terrace a back furrow is made at the ridge top and successive furrows are thrown toward it until the entire width of the ridge has been covered, thus increasing the ridge height and, if desired, the width at the same time.

ABSORPTION

Increasing absorption by mechanical methods should be an integral part of the erosion-control plan, whether used independently or in combination with other mechanical measures. Probably the method most applicable to all conditions is contour cultivation, which provides numerous small depressions or reservoirs in plow furrows, in wheel marks, or behind lister ridges to retain water and promote absorption. Deep plowing in some soil types, particularly those subject to excessive packing or other impervious conditions, provides an absorptive mantle of greater depth. Chiseling or subsoiling to break up intractible strata of hardpan, or to shatter the subsoil to permit deep penetration, is an effective measure on adaptable soil types. Subsoiling terrace channels on some of the soils of the Piedmont section of the Southeast

FIGURE 3.—Maintaining the channel-type terrace by plowing.

with deep-cutting chisels to a depth of 24 inches or more has increased absorption to such an extent that in some cases there was no discharge at the terrace end during the first year after the operation.

Level terracing in the semiarid dry-farming sections is one of the most effective measures for increasing absorption and decreasing erosion. Drought conditions frequently make such measures necessary to insure establishment of a controlling vegetal cover. Data from the Stillwell, Okla., Soil Conservation Experiment Station indicate that crop failures from drought are reduced from six to three in a 10-year period by impounding all run-off with level terraces. Caution must be exercised here also to see that the practice is correlated with soil type and other factors, since impounding on impervious soils will result in drowning crops or control cover.

Before any mechanical measures for promoting absorption can be made fully effective, the soil itself must be in condition for optimum absorption and percolation. The porosity of a soil that was originally

highly absorptive may have been seriously reduced as the result of depletion of organic matter and improper tillage. The addition of humus is essential to preserve or restore absorptive characteristics. Field tests on basin listing under identical soil and slope conditions showed 40 to 60 percent more absorption where leguminous cover crops had been grown and turned under each season for 10 years, as compared with a portion of the same field where no cover crops were grown and no organic matter returned to the soil. The correlation of vegetative and mechanical measures is nowhere more important than where absorptive methods are being considered. Tillage performed under the proper moisture conditions promotes the breaking up of hard impervious lumps to smaller particles and provides more voids in the soil mass for increased infiltration. Plowing when the soil is too wet or dry often produces the opposite results, and the trampling of livestock on muddy field surfaces may result in a puddled condition of soil that makes it practically impervious.

Basin listing is listing with a machine having an attachment that forms an earth dam across the lister furrow at intervals of 15 to 25 feet. The practice is superior to ordinary listing under some conditions, especially when used on fallow to store and absorb all run-off. It has little if any advantage when used in preparation for planting row crops, since the dams are soon destroyed by cultivation; but in preparing wheatland for planting it has proved practical when used in connection with a special drill that seeds a row on each side of the lister ridge. It has the further advantage that strict adherence to the contour is not essential. With this practice, rows varying from the contour by 3 or 4 percent are still effective because each dam retains its water in place. Also, in case of a break-over in low places only the water in the broken sections is allowed to escape.

An important principle to be recognized in the laying out of contour rows is to avoid concentration of water on critical spots in the field. Contour rows are generally laid out parallel to terraces, and the rows have a slight grade corresponding to that of the terrace. While the grade will produce only a low velocity, the rows can be used effectively to divert normal run-off laterally across the field. A method holding some promise has been developed by Soil Conservation Service engineers in Mississippi whereby the interval between terraces is divided into two or three approximately equal areas by guide rows located between terraces on grades such that the water will be drained from the steeper parts to the gentler slopes of the land lying between terraces.

SPECIAL MECHANICAL METHODS

Bench terraces are one of the oldest mechanical methods of erosion control, and have been used for many centuries in thickly populated countries where economic conditions or even the maintenance of a livelihood necessitated the cultivation and preservation of steep slopes. Population density and other factors do not as yet demand the cultivation of excessively steep slopes in the United States except under special conditions. Cultivation of field crops on steep bench-terraced slopes has been practiced in some sections of the South for several generations. In the highly productive citrus lands in Cali-

fornia, bench terraces have been used, to a limited extent, on steep valleyside slopes. There are other places where bench terraces used in connection with production of such valuable specialized crops as vineyards and orchards are practical in restricted areas.

The ordinary method of producing the bench terrace in the Southern States was to construct a series of small ridges on terrace intervals across the slope, usually on the contour or to a slight grade. Erosion on the strip between two ridges lowered the elevation of the upper side, and the eroded material was caught by the ridge on the lower side to form the bench. As deposition took place the ridge was raised successively higher and was protected with field stones, rubbish, or a natural growth of vegetation, which was allowed to remain in place. The process was hastened by plowing downhill. After several years the result was fairly level benches with steep protected risers between. Several methods of handling surface run-off were practiced. In some cases it was allowed to flow across the bench over the edge of the steep riser, and to the next bench below; in others the ridge at the lower edge of the bench was maintained at a height sufficient to divert the water and discharge it at the end of the terrace. Some farmers plowed a shallow water channel in the surface of the bench several feet uphill from the lower edge to conduct water to the end of the bench and away from the field.

The California, or Reddick, terrace is produced in much the same way except that no ridge is used to start benching action. Instead, rows of trees are planted on an irrigation grade across the slope. Cultivation between the tree rows leaves a strip of vegetation in the row that acts as a balk to promote soil deposition to form the bench above the tree row. Cultivation and the plowing of irrigation furrows between the tree rows further promotes benching action. When the bench is completed the trees are about half way down the steep side of the riser, which is amply protected with vegetation.

Experiments are now being conducted with bench terraces in Puerto Rico, where it is frequently necessary to cultivate slopes up to 40- or even 50-percent gradients in order to support the dense population.

Irrigation water frequently produces serious erosion, particularly where irrigated orchards occupy steep slopes. In several locations in California and Utah, orchards are irrigated by water discharged from head ditches. In such locations it is the usual practice to allow the water to flow for long periods in order that all parts of the slope will receive sufficient moisture. By the time water has sufficiently irrigated the lower portions of the slope it has usually been flowing across the upper portions for several hours or longer, depending on the length of the slope. During this period excessive erosion may have occurred on the upper portions. Erosion control in such situations becomes a problem in the proper application of irrigation water.

At Placerville, Calif., where slopes ranging up to 30- or 40-percent gradients are occupied by pear orchards, several successful and practical demonstrations of the underground distribution of water to a point near the place of application have been installed. Various methods of application may be used, depending upon the situation. For instance, water may be delivered from the pipes to head ditches

at intervals down the slope where it has a much shorter run in reaching all parts of the irrigated area extending down to the next head ditch below. In other instances, the water may be discharged at intervals along the pipe line to flow laterally, at a low gradient, across the slope without danger of causing erosion. Any practical method to reduce the length of run of the water over unprotected surfaces, or to reduce the gradient of flow, is effective in reducing erosion. Where there is enough water to grow a cover crop and at the same time supply sufficient moisture for the trees, the erosion hazard can be eliminated in this way, but as a usual thing the orchard acreage has been so extended that there is not sufficient water available for both purposes. Serious erosion is also taking place in a number of

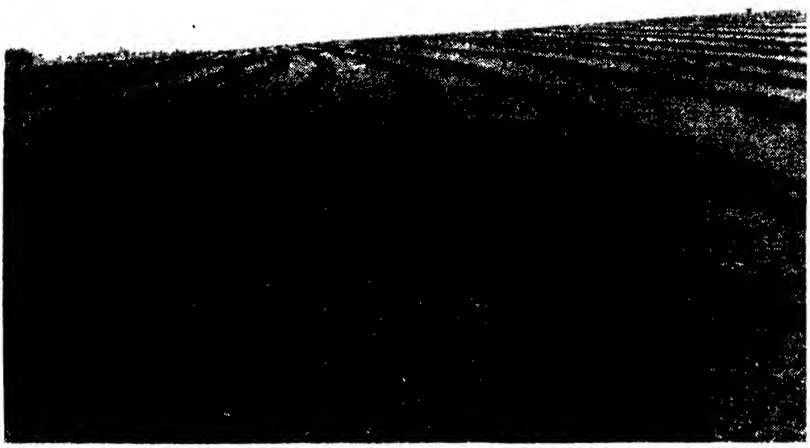

Figure 4.—Contour furrows on pasture slopes.

western localities on steep slopes used for potatoes and other crops, grown in rows running downhill, where irrigation water follows the interrow furrows.

CONTROL IN PASTURES

Mechanical erosion-control measures in pastures generally consist of structures or practices that will aid the establishment and growth of vegetation. The end sought most often is the retention and distribution of moisture, although diversion away from critical places may sometimes be effective. Tillage and fertilization to improve the condition of the soil are practiced under some conditions, particularly where grasses tend to become sod-bound. Structures such as terraces for protection while vegetation is being established may also be feasible for new pastures (fig. 4).

Contour furrowing is often used for retention and distribution of

moisture. Furrows or ridges are constructed across the slope on the contour and act as small impounding basins to promote additional infiltration. The size and spacings of furrows must be dictated in many places by judgment since there is very little experimental data on the subject. Several factors will, of course, influence spacings. These include the effect of soil characteristics on the rate of infiltration, as well as on the depth of penetration and the lateral movement of water; the cost of construction; the importance of additional moisture to last over drought periods; and the amount of sod that would be destroyed by construction.

Furrows may be made any size that is convenient where it is not desirable to retain all run-off on the pasture area. Water in excess of their impounding capacity will flow from the lower side of the furrows without excessive damage to the structure. When better distribution is required a system of spreaders may be used in connection with the furrows. The spreader is a small diversion channel or earth dike so placed that concentrated run-off in natural channels is diverted at intervals and discharged through openings onto the more sparsely watered areas. Contour furrows placed between the spreaders insure equal distribution of moisture over the entire slope.

In some locations it may be desirable to retain all run-off except that from the most intense rains. Ridges are generally used under these conditions in order that the area covered by impounded water may be as great as possible. It is obvious that ridge height must be in proportion to spacing intervals, slope, and run-off in order to provide a definite capacity. To avoid the possibility of losing all impounded water should a series of breaks occur in the ridges, small earth dams are thrown up above and at right angles to the ridge line at intervals of 20 to 100 feet to divide the impounded water into separate portions. By making the dams lower than the ridge, ordinarily about two-thirds its height, they are made to serve also as equalizers, permitting equal distribution to adjoining reservoirs should one be overloaded by concentration in the flow from above.

Terraces or diversion channels may be used to protect critical areas, such as very steep slopes, bare or eroded places, or the heads of active gullies. Complete terrace systems may sometimes be necessary to to protect severely eroded pasture areas or to provide protection while new pastures are being established. In either case a small modified terrace cross section is ordinarily sufficient to meet the requirements. Treatment of an entire watershed in this manner may reduce run-off sufficiently to have considerable flood-control value.

Conditioning the soil by mechanical means may often be advantageous where a large part of the topsoil has been lost by erosion, and in impervious or closely packed soils. Deep tillage by chiseling 24 to 30 inches deep at intervals has proved effective in some places when performed on the contour. Spacings depend on a number of factors. Complete seedbed preparation may be necessary when new pastures are planted. A method that generally gives satisfaction is to plow in such manner as to form small, flat, parallel ridges on the contour, 8 to 12 feet wide, with slight channels or water furrows between for the storage of moisture.

Mowing, in addition to destroying weeds and other undesirable

plants, provides a mulch and promotes the right kind of vegetation if performed at the proper season. In establishing vegetation on severely eroded, galled spots, nothing appears to be quite so successful under all conditions as a mulch cover, by which velocity of run-off is reduced, more moisture is retained in the soil, seeds are held in place, and protection against grazing and evaporation is provided for young plants.

RANGE CONTROL

The depletion of native cover by overgrazing on range land is a common cause of erosion. In many places, regulated grazing is the only control measure justified and it should be included as a necessary and integral part of any erosion-control plan. Fencing to control grazing, or to exclude livestock from critical areas, will prove economical under many conditions. Some State laws permit free grazing of any unfenced range whether held in private or public ownership and fencing is necessary to control grazing where such laws exist.

The development of well-distributed watering places is also essential to the control of grazing. Reservoirs, or stock tanks, formed by impounding dams on small contributing watersheds may, in addition to furnishing water for stock, promote moisture conservation, furnish water for irrigating supplemental feed crops, and decrease run-off.

Water spreading for better distribution and increased absorption by contour furrows, ridges, and dike spreaders is adaptable to range land in the same manner as described for pastures. Since most of the present range lands are located in the more arid sections of the country, water spreading and mechanical conservation measures assume importance when soil, topographic, and economic conditions permit their use.

Flood irrigation by damming large gullies in wide, flat valleys and diverting the water to the valley floor produces good results where topographical conditions permit economic installation. Run-off from freshets that occur only once or twice a year is diverted laterally across the valley behind earth dikes which have openings for discharge at suitable places. Flow across the valley is regulated and distributed by means of dikes constructed of earth, stone, or brush. Remarkable increases in native vegetal growth have resulted on many such irrigated areas, which provide, in addition to gully control and stock water, grazing for increased numbers of livestock, with consequent reduction in numbers on adjoining overgrazed areas.

Gully control by means of check dams and structures for prevention of overfall cutting are also used on range lands under special conditions, but their application is primarily for gully control and their nature and use are described under that heading.

CONTROL OF EROSION IN CHANNELS

Run-off must be expected from all agricultural land regardless of the erosion-control measures used. Provision must be made to conduct the excess water to a stabilized channel. Surface water naturally becomes concentrated in channels in such quantities that special attention must be given to them if they are to be protected from erosion. Channels may be considered as minor and major.

Minor Channels

Minor channels are those that carry the water from a small area such as a terrace system. They can be protected from erosion by vegetation or by simple structures. In the preparation of these channels, advantage is taken of all natural depressions that have a good vegetative covering, or on which cover can easily be established. If natural channels are not available or are not suitable, artificial channels are created where they will interfere least with the farm operations. Run-off is often diverted from natural channels that are unsafe to other channels that have a good cover. If possible, the diverted water is emptied in wood lots or pastures, and an effort is made to avoid concentration. Whenever natural channels or vegetated areas are used, the grade over which the water will flow must not exceed the safe limit for the existing condition of soil and cover.

The artificially created minor channels are of two types, high-velocity and low-velocity channels.

Low-Velocity Channels

In designing a low-velocity channel an effort is made to limit the velocity of flow in the channel to an established safe maximum for the type of protective cover to be used. This is accomplished by making a wide, shallow channel so that the flowing water will be in contact with a large area and its velocity will be limited by friction. The type of channel used depends upon the value of the land, the condition of the soil, the type of vegetation that can be used, and the degree of effectiveness desired.

Meadow strips, a natural drainage protected by grass or other close-growing perennial vegetation, are used as channels wherever possible because of the ease and economy with which they may be established and also because they produce a crop of hay. In establishing a meadow strip, a slight natural depression is selected that may, if necessary, be straightened and reshaped. It is seeded to a permanent hay crop. Meadow strips may be crossed with farm implements provided tillage implements are raised and the cover is not destroyed. They must be given time to become established before outside run-off is turned on them. Where adaptable they are almost universally used for terrace-outlet channels if they can be established prior to the construction of the terraces. Sometimes it is possible to divert the water from a terrace system into a temporary outlet until a meadow strip is established.

When a meadow strip cannot be used, a narrower channel is carefully constructed to insure accurate control of the velocity. A cover more resistant to erosion than that in the meadow strip may be necessary. The time required to provide a safe channel is one of the important factors in selecting the protective cover in this type. Close-growing grasses that form a dense turf, such as Kentucky bluegrass and Bermuda grass, are commonly used. Bluegrass sod is usually cut out in narrow strips with which the ditch is either wholly or partially lined. Bermuda grass may be established by sprigging, sodding, or seeding. If the soil is poor, it should be fertilized to aid in the rapid development of the grass. Plantings of low wild shrubs may

be utilized in some locations. Another method of establishing vegetation is to seed the channels and protect the seed with a mulch of straw or other litter, but the conditions under which this method may be used are rather limited. Small breaks in old channels are repaired by filling with burlap bags containing chunks of sod. By the time the bag rots away the sod is well established.

High-Velocity Channels

When the grade of the channel becomes too steep to permit the practical use of a low-velocity channel, a high-velocity channel is used. In this case an effort is made to produce as high a velocity as possible in order that the channel may be as small as possible and require a minimum of the expensive materials that must be used when the safe limit for vegetation is exceeded. Concrete has been used extensively, and asphalt has been tried experimentally. This type of channel is often necessary at the lower end of a low-velocity channel if a steep

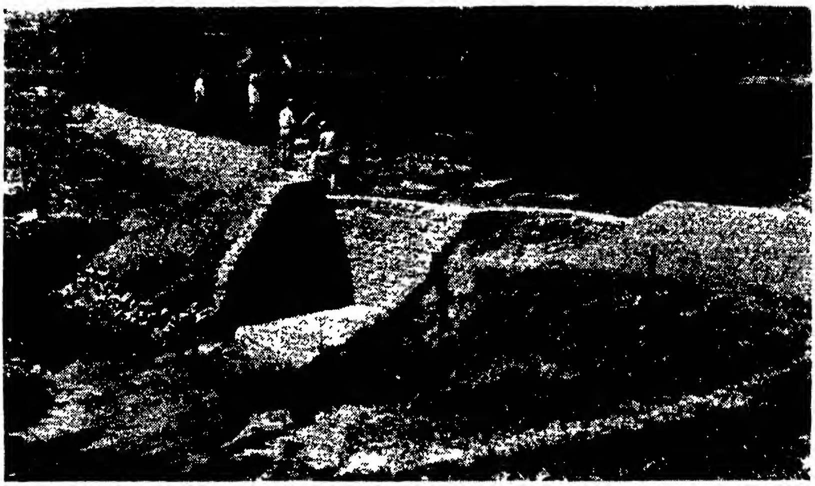

Figure 5.—A masonry dam protecting a gully head that was rapidly approaching the highway and cultivated field above.

slope occurs on the bank of a stream, or if there is an abrupt change of slope. In some cases, such a channel may be substituted economically for a low-velocity channel if the topography is such that the channel can be sufficiently shortened by leading it down the steepest part of the slope.

Major Channels

Major channels may be divided into those having intermittent flow and those having continuous flow.

Channels With Intermittent Flow

In the type having intermittent flow the most serious problem occurs at the head where a vertical drop is present. In order to

arrest headward cutting these overfalls are protected by dams whenever the value of the land endangered justifies the expenditure. The dams may be located a short distance below the channel head and constructed to a height that will pond water over the overfalls, or the dam may be located adjacent to the overfall for mechanical protection. Other structures downstream from the overfall may be necessary to raise the bed of the channel in order to prevent side overfalls from developing, and to protect upstream structures from undercutting (fig. 5).

Permanent dams that pond water either in the channel or at the overfall are called soil-saving dams, since soil collects until the pond

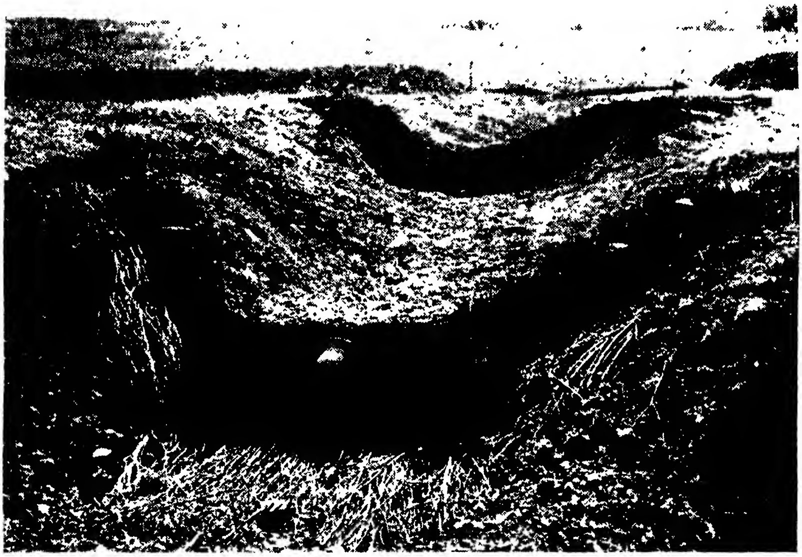

FIGURE 6.—Low wire and brush dams constructed for temporary protection to the gully while vegetation is being established.

is filled. Two types of dams are commonly used, the notch spillway and the drop inlet. The notch spillway is usually built of rubble masonry or reinforced concrete. The drop inlet is an earth dam with a tube of reinforced concrete through it. A riser on the tube extends nearly to the top of the dam, so the pond must be nearly full before any water can flow out.

Temporary dams are sometimes used as barriers to stabilize the flow line of gullies while vegetation is being established (fig. 6). Since their need is limited to a period of 2 or 3 years, such native materials as brush, straw logs, or loose rock are generally used. While expensive permanent construction is not usually necessary under these conditions, such structures must be reasonably secure and carefully designed to insure that they remain in place until vegetation becomes established. Overfalls on temporary dams must be kept extremely

low to avoid the cutting out of deposited material after the dam fails. Such a temporary dam for gully control is sometimes referred to as a check dam, a term that to some people implies the function of storing water. Temporary dams are not used for water storage in soil conservation work, however, since they would be uneconomical and dangerous where large numbers of dams are used on a watershed.

Permanent dams of the low overfall type are sometimes necessary to establish and maintain a flow line for the channel.

Channels With Continuous Flow

In the case of a stream having continuous flow, most of the damage is done by bank cutting or meandering of the stream, which often destroys valuable bottom land. On raw banks it is usually necessary to construct jetties, wing dams, or riprapping before vegetation can be established. Streams are often straightened to cut off critical bends, if such straightening will not create other hazards further downstream. In many cases small storage dams are incorporated into the control measures used on the smaller streams if the topography is such that they can be used. These dams are valuable as a water-conservation measure and for recreational and stock-watering purposes.

GULLY CONTROL

Gullies are channels formed by erosion that either have lost their vegetative cover or never had one and therefore offer little or no protection against erosion. Actively eroding gullies usually require some mechanical means of protection before they can be controlled. The control of run-off water in the narrow channel of a gully is usually both difficult and expensive. The practice of intercepting run-off with diversion ditches or terraces, before it enters the gully is widely followed wherever possible in order to lead the water to some place that can be protected more easily than the original gully. In many places the diversion of the excess water from the gully is the only control measure needed, and in all cases the control of the gully is very much simplified by this method.

When the water cannot be diverted out of a critical gully it is necessary to build structures to protect it from further cutting. The structures and the method of using them have been explained in connection with the control of major channels having an intermittent flow.

The use of any mechanical measures for gully control must be carefully justified from an economic standpoint. If the land is already ruined by gullies there is little need to spend money for their control and stabilization. Protection from grazing and fire damage and assisting native growth may effectively control the area within a few years. On the other hand, deep gullies cutting headward through fertile land or endangering improvements, such as highways and buildings, may justify considerable expenditure for control purposes.

COMBATING WIND EROSION

Pressure by wind is directly proportional to the square of its velocity, which indicates why so much force can be exerted by strong winds.

It is readily conceivable that wind is capable of transporting or moving vast quantities of material when it is considered that a speed of only 20 miles an hour produces a pressure of approximately 1 pound per square foot. A small reduction in velocity, therefore, will cause a proportionately greater decrease in pressure. Thus, if the velocity of a wind that is carrying materials can be reduced by obstructions to its sweep, it will be forced to deposit some of the material. Similarly, reducing the velocity reduces the power of the wind to remove material.

It is also obvious that if the size of the material can be increased, much less will be carried at a given wind velocity. This is an important principle utilized in combating wind erosion. It is not possible to reduce wind velocities appreciably over large areas, but it is possible to put cultivated soil in such a condition that the clods or lumps exposed to the full sweep of the wind will have sufficient size and weight to resist being transported.

Any obstruction to the wind's sweep such as lister ridges, clods, or stubble will break the velocity at the ground surface and cause eddying and back drafts that prevent small particles being moved. Such obstructions also promote drifting on the leeward side, which soon fills the depressions. When the surface becomes smooth, removal by wind action begins anew and the listing or tillage operation must be repeated. All high obstructions to the wind's action may become hazards that cause drifting in sections where large wind movement of soil material is in progress. Fences, buildings, idle farm machinery, or trees may promote objectionable and dangerous drifting. There are numerous examples of roads completely covered by drifted material along fence rows, of buildings submerged, and of trees killed.

The fundamental causes of soil movement by wind have not as yet received much scientific study, and causative factors are still largely a matter of speculation. The elementary cause, of course, is the action of wind on smooth surfaces of loose, dry soil unprotected by vegetation. It has been noticed that very light and very heavy soils, such as sand and clay, are the most susceptible to blowing; also that drifting is not a spontaneous action over a wide area but originates at localized spots or focal points and spreads rapidly. Suggested control measures are based on the principle of checking soil movement in its early stages.

Effective permanent efforts toward wind-erosion control must center around the maintenance of a good vegetative cover, continuous on range land and during critical periods on croplands. In the absence of an adequate cover of vegetation or its residue, mechanical measures must be used.

Tillage Methods

Listing is considered one of the most effective types of tillage for establishing a ridged and cloddy surface that will offer a maximum resistance to wind. It may be either open or basin listing, depending on requirements. Basin listing is more effective on fallow land but has less advantage where cultivated row crops are used because the pockets are soon destroyed by cultivation. Listing may be either straight or on the contour. Basin listing is well adapted to straight farming where moisture conservation is desired and strips have been

laid out crosswise to the prevailing wind. Under this condition ordinary open lister rows would serve as channels to carry away water from certain sections of the field instead of conserving it. Under contour tillage open listing would, of course, serve as a means of storing water as well as aiding in the control of erosion by both wind and water.

Other tillage machines used to produce a cloddy trashy surface are the one-way disk and the duckfoot cultivator. The one-way disk is of value in that it mixes surface soil with any vegetative cover that may be present and leaves the soil in a somewhat roughened condition. It is particularly useful on heavy stubble. The duckfoot cultivator leaves the soil in small ridges mixed with trash and clods that protect the fine earth from blowing and drifting. It is, of course, essential that the stubble should not be burned if a trashy cultivation is desired.

Deep tillage is often necessary in order to produce a cloddy, lumpy surface. It is also important to limit tillage operations as much as possible to periods when conditions are optimum for the control of soil drifting and blowing. For example, it is usually far better to allow a stubble field to stand over winter than to plow it in the fall and have it "blow" during critical periods.

Wind Strips

An important practice recommended for controlling soil blowing is strip cropping, division of fields into alternate strips of fallow and grain. The strips ordinarily average about 10 rods or less in width. When the seeded parts have made sufficient growth to protect the soil, the intervening fallow strips are cultivated by tillage methods previously described to produce a lumpy surface. To be most effective wind stripping should be practiced on a community basis; otherwise soil movement from unprotected fields will continue and may destroy the control measures on other fields. It is important that the best cultural methods be adopted for summer-fallow strips to insure as much trash cover as possible and to maintain the soil in lumpy condition. The strips should be laid at right angles to the prevailing wind if wind-erosion control is the primary objective and be placed on the contour if water-erosion control is also of importance.

The level or absorptive-type terrace used for the conservation of moisture indirectly aids in wind-erosion control. The actual impediment of the terrace ridge to the wind is negligible, but the additional water retained in the soil will aid in producing a vegetative cover that acts as a mechanical control measure for wind-erosion.

Dunes

The formation of dunes or drifts through soil blowing may do tremendous damage in addition to the actual removal of soil from the fields. The drifts are formed in the same manner as the sand dunes found in desert regions, or along particularly sandy and wind-swept shores. Dunes are constantly shifting or reforming and thus encroach on more and more territory. They frequently hamper traffic and by filling highway ditches they destroy necessary drainage.

Careful study and observation coupled with field experience have demonstrated that the same forces responsible for forming dunes may be used to dispose of them. Of primary importance, of course, is

prevention of their formation, which can be done by preventing soil drifting. Where some drifting still persists in spite of preventive measures, it may become necessary to construct such obstacles as fences or weed rows at strategic points to prevent dune formation at undesirable places. Such obstacles cause a sudden reduction in wind velocity, which induces deposition of some of the material being carried, and ultimately the formation of a drift or dune. The location of the obstacle with respect to the prevailing wind will determine the location of the dune. Snow fences contribute to the formation of snowdrifts in a similar manner.

Where it is desired to remove an existing dune there are several methods that have been successfully used. One of these is dependent on the fact that increased velocity enables the wind to carry a greater load. Sandbags or similar barriers are placed along the crest of a dune in such a way as to leave an open space between bags. The wind passes through these narrow openings at a higher velocity, picking up material from the crest as it passes. The material will be dropped later on but usually will not reconcentrate unless it meets some barrier. The sandbags or other obstacles may be shifted from time to time so that the dune will be evenly removed.

Another method takes advantage of the fact that when the lip, which usually forms on the leeward side of a drift, is destroyed or broken certain eddies that contribute to the building up of the dune are eliminated and the dune will gradually disintegrate. Any machinery such as a harrow or blade can be used to break up the lip. It is, of course, necessary to continue the operation at intervals, because the lip is continually reforming.

IN THE PAST the failure of certain erosion-control practices such as terracing when applied alone has taught agricultural scientists and engineers that no one practice is likely to be sufficient by itself. Usually several practices must be combined to fit a particular area or farm. The first part of this article discusses broadly what is needed for a coordinated attack on the erosion-control problem in the dry or subhumid regions of the United States and in the humid regions. The second part tells in detail just how such a coordinated approach was carried out on three representative farms in North Carolina, Illinois, and South Dakota.

The Coordinated Approach to Soil-Erosion Control

By Ervin J. Utz [1]

EROSION and erosion losses are not due to one or even a limited number of causes, and no one remedy or preventive measure can be regarded as a panacea. A doctor must first diagnose the ills of his patient, determine their cause, and then prescribe the remedies to correct the trouble at its source. Likewise, in checking erosion, a thorough diagnosis is necessary before proper preventive remedies can be prescribed to correct the existing conditions.

In this article the two major regions in the United States, the subhumid and the humid, are considered in a general way, to bring out the broad outlines of a conservation policy. Then three actual farms, chosen at random, are described in detail to show how various conservation measures dovetail together to meet the needs of specific land areas. It will be understood that conservation of soil and conservation of water are so intimately associated with each other that a discussion of the one must necessarily include the other.

THE SUBHUMID REGIONS

In much of the subhumid area devoted to grazing, which includes much of the Great Plains, neither erosion nor run-off was a serious problem so long as the native grasses and other vegetation formed a relatively dense cover on the land. Restricted grazing will, in the majority of cases, permit grass recovery sufficient to prevent further soil deterioration, and in time may result in improvement approaching original conditions. In areas where deterioration has proceeded almost to the point of completely destroying vegetation, the only remedy seems to be the installation of mechanical structures to retard

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run-off and make more moisture available for the recovery of protective vegetative growth.

Contour furrows, to prevent concentration, and water-spreading devices, to disperse water already concentrated, are material aids to recovery in critical range and pasture areas. No rule of thumb, however, can be provided in the application of these supplementary measures, because of the varying conditions of topography, soil, and cover. Each situation presents a problem that must be solved on the basis of the particular conditions.

The problem in the cultivated areas of the Great Plains is not so simple of solution. The native vegetation has been destroyed entirely, and the erosional processes have changed soil conditions to a much greater extent. The sifting action of wind erosion has removed the more productive components of the soil to the point where former climax types of vegetation are no longer adapted.

Areas unsuited to cultivation must be revegetated. Here the services of the ecologist, the agronomist, and the range specialist will be required to meet the challenge. The reestablishment of a permanent protective cover having economic value will require both engineering and agronomic assistance. Water must be conserved to provide favorable moisture conditions, and on critically erodible areas, such as loose sand, the assistance of companion or nurse crops will be needed to protect the new seedlings from destruction by abrasive shifting sands during the critical spring months when high winds prevail. The revegetation and control of these critical areas is tremendously important. If these critical lands cannot be permanently stabilized, they will constitute a hazard to adjacent range and cropland. No single control method will suffice to meet the need, and different combinations will have to be used where different conditions prevail.

The lands now considered suitable for cultivation in the subhumid areas present a most varied and difficult problem. The prevailing crop outside of the irrigated areas is wheat. Can the continuous use of land under a wheat fallow system be considered a permanent type of agriculture? The agronomist and soil scientist must provide the answer from the point of view of erosion control and the maintenance of soil productivity.

Assuming that such a system is satisfactory, the engineer will be called upon to provide such water-conservation and soil-stabilizing measures and devices as terracing, contour cultivation, and gully-control structures, and to develop equipment which will facilitate farming operations under such a system of tillage. The agronomist will work out an adequate system of using crop residues, which, either left standing or incorporated into the upper layer of soil with part of the stems projecting, will provide a substantial protection against both wind and water erosion. The entomologist may also be needed, should such a system create an insect hazard. In periods of subnormal rainfall, supplementary crops must be used both as a protection against wind erosion and to provide some economic returns when moisture conditions are unfavorable for wheat production. Such conditions have been common in the Great Plains during the past 5 or 6 years.

Along with these determinations must go an intensive educational program, not only to acquaint farmers with the methods and practices to be followed, but to impress upon them a profound appreciation of the need for water conservation and the importance of determining whether or not the moisture content of the soil at planting season is sufficient to warrant seeding. The success of such a farming system will depend to a great extent on the judgment of the operator with respect to what crop to use under certain conditions and the proper time for planting.

If the wheat fallow system is not to be considered a type of permanent agriculture for this vast area, then the agronomist and land specialist are faced with the problem of devising another system that can be applied economically and that will give needed protection to the soil and permanently maintain its favorable composition. Regardless of the system developed, water conservation measures will be determined by the cropping program that is to be followed. Probably nowhere else in the country is there such a delicate balance between moisture conditions and crop production as in the Great Plains and other similar areas in the West, such as the Big Bend country in the Columbia River Valley.

THE HUMID REGIONS

In the humid sections, wind erosion is a minor factor, but in the Corn Belt and in the great southern cotton area where clean-tilled crops play such an important part, water erosion and floods have exacted an enormous toll. In much of the cotton-growing area, certain conservation methods, such as terracing and contour tillage, have been practiced in varying degrees for many decades but have been found inadequate to conserve the soil and reduce flood and silting hazards. Here a large percentage of the cultivated land has been devoted year after year to clean-tilled crops, principally cotton and corn, and locally tobacco and vegetables. Large acreages have been so severely eroded that they have been abandoned and allowed to revert to natural vegetation of grass, weeds, and forest.

Part of the continued erosional losses on land already terraced has been due to the inadequate construction and to the relatively high gradients of the terrace channels. Inadequate terrace outlets have also been responsible for severe gullying in some areas. A limited use of winter and summer legumes has proved inadequate as a protective cover for erosion control and as a means of maintaining either the humus supply or a satisfactory soil structure. Here again, the conservationist, the agronomist, the forester, and the engineer must aid each other in developing ways and means whereby the soil wastage may be reduced to the point where soil building will keep pace with soil losses. The fact that terraces have failed to provide the panacea is no indictment of a terracing program, nor is the failure of legume cover crops to accomplish the impossible under existing conditions a reason for condemning their use. Each has a part to play in the program of soil conservation, but they must be improved and supplemented by other measures designed to correct deficiencies in the program.

The engineer is improving terrace designs, and in cooperation with

the agronomist is providing specifications for adequate outlets, so that excess run-off may be safely carried to stabilized streams. The agronomist, soil scientist, and soil conservationist are developing cropping systems that will provide for a smaller proportion of clean-tilled crops in the rotation and a higher percentage of close-growing crops of greater density. In redesigning the cropping pattern, the agronomist is also providing for strip cropping, contour cultivation, and other cultural practices. The forester is carefully developing management plans for the best utilization of land for forest cover. The soil conservationist is coordinating all individual approaches in the development of plans for individual farms, so that one practice or method will supplement another, and a proper combination will give each one its maximum effectiveness. At the same time, coordinated plans are developed with the objective of securing the maximum protection at the lowest possible cost for installation and maintenance.

Land not suited to the production of clean-tilled crops, because of topography, soil, or present extent of erosion, is retired to permanent pasture or hay crops, or planted to trees, which in time will provide additional farm income as well as protection from erosion. Shrub plantings are used also, selected with a view to providing suitable cover and food for game birds and animals. Wildlife has a dual function—insect control and recreation or an income from recreational uses. Shelter and food plants for wildlife species may be provided on some areas that frequently have little protection from erosion, such as gullies in woodland areas and field borders.

In many respects the problems in the Corn Belt are different from those of the great cotton-producing areas of the South Atlantic and Gulf States. Rotations are generally more satisfactory from the viewpoint of erosion control and maintenance of soil productivity, because of the large numbers of livestock raised and the necessity for growing a considerable acreage of close-growing crops to provide roughage. The use of close-growing erosion-resistant crops has been due generally to the farming systems and not to particular thought on the part of the farmer as to their value for erosion control. Most of the area is laid out in sections, and farm and field boundaries generally follow section lines, with no general regard for topography or differences in soil characteristics.

This condition has led to straight-row farming and the use of large machinery. Probably the most difficult problem in the Corn Belt is the introduction of contour farming. Without contour farming, several of the most effective conservation measures known, such as terracing, strip cropping, and contour furrowing, cannot be used. For the most part, the Corn Belt fields are relatively large, and where the entire slope is devoted to row crops, with the rows running up and down the slope, erosion has taken severe toll. Although the amount of land to be retired from further use for clean-tilled crops is not proportionately large in this section of the country, the adoption of proper land-use methods incident to the establishment of longer rotations will result in a considerable shift from clean-tilled crops to the less erosive types, particularly from corn to legume-grass hay crops, and to permanent pasture.

Because erosion has not progressed quite so far in the Corn Belt, there is greater opportunity to work out a constructive and satisfactory land-use program. In the more rolling parts of the Corn Belt, considerable acreage is devoted to permanent pasture. Much of the present pasture area is land that at one time was used for cultivation and was retired as erosion proceeded to the point where cultivation was no longer profitable. The grass is generally of rather low quality, owing to the fact that farmers have felt too generally that no soil-improving treatment was necessary on pasture land. In some of the more rolling sections, the steepness of slope and shallowness of soil are such that timber is the most adaptable cover.

In the Corn Belt, as in other areas, proper land use based on an inventory of slope, soil, and erosion conditions on the individual farm is fundamental to adequate planning for sound conservation programs. One of the important conditions of proper land use is the realignment of field boundaries to conform as much as practicable to natural areas of soil type and topography. Without such realignment, contour cultivation becomes unnecessarily difficult.

After proper land use has been determined, the application of mechanical and vegetative controls to correct the weaknesses of previous farming practices can be outlined. The complementary use of vegetative and mechanical measures will be needed in most instances. Under certain conditions, where the soil is not highly erodible, a good rotation may suffice; where conditions are not quite so favorable, contour cultivation will be required in addition to an adequate rotation system. Where slopes are longer, or where land conditions are less favorable, terracing or strip cropping, or both may be required to stabilize the soil adequately. Vegetative and engineering practices, here as elsewhere, must be coordinated to accomplish the desired results without disrupting the farming system too much.

Radical changes in the type of crops grown or in the equipment to be used should be considered carefully, and such changes should be made over a period of years.

As emphasized above, no one erosion-control measure is a general panacea, and no one measure, however good generally, can be applied under all conditions. There are economic as well as physical limitations to the use of control measures. For example, the construction of broad-base Mangum terraces on a 20-percent slope in the Piedmont section of Georgia, where the land is used for cotton or other row crops, would not be feasible. Most of the topsoil on the field would be used in building the terrace ridges, leaving little of the most productive surface soil available for crops, and the cost of constructing and maintaining terraces on such steep land, in proportion to the crop returns, would generally make their use unprofitable. On the other hand, the use of bench terraces on a 30-percent slope in the irrigated citrus orchards of California might be extremely profitable as well as requisite to adequate soil conservation.

The question is often raised as to how much an operator can afford to invest in erosion control. In most areas, control measures may be considered under two headings—those with a relatively large initial cost, that once installed require only maintenance; and those that become a part of the farming system. In the first group are such

practices as terracing, contour furrowing of pastures and range land, and planting of trees, grasses, etc., for permanent use. Most of these control measures, while requiring maintenance, do not require replacement. Such control measures as rotations, strip cropping, use of cover crops, contour cultivation, fertilization, liming, and the like, become a part of the regular farming system. No cash outlay above ordinary farm operation costs is required except for fertilizers, lime, and in some sections seed for cover crops.

ILLUSTRATIONS OF COORDINATED PROGRAMS

The Soil Conservation Service is cooperating with hundreds of farmers in all parts of the country in demonstrating efficient, practicable soil-conserving practices and methods. In developing individual farm plans, the technicians of the Service work out all details with the cooperating farmer. Two maps are prepared, one showing the physical features of the land and present land use and the other the plan for better land use based on the physical characteristics of the farm, the climatic environment, and the economic situation. A complete plan of conservation operations is also prepared jointly by the Service technicians and the farmer, to serve as a guide for the farmer in the installation and maintenance of erosion-control practices and methods.

Three farms have been selected at random to serve as samples of individual farm plans designed to control erosion—one from the Southeastern States, one from the Middle West, and a third from the Great Plains.

Farm Near Providence, N. C.

The variable soils of this farm (fig. 1), coupled with different slope conditions and past practices in management, have caused development of serious erosion problems. The productivity of some of the fields was reduced to the extent that the owner retired parts of the cropland to woodland and other voluntary growth—that is, cultivation was not continued and no direct provision was made for care of this land.

The predominating soil type is Cecil clay loam, which is a fairly productive soil in its original condition. This farm, however, has been operated for many years, and soil conservation apparently has not been considered important by the owners and operators. Because most of the farm consists of B slopes (3 to 7 percent), and ranges from undulating to rolling, ill-advised practices in the past have allowed the removal of 25 to 50 percent of the topsoil by erosion (class 3 erosion). In places, the land is severely gullied. Such areas approach or come within the class of erosion designated as 3, under which from 50 to 75 percent of the topsoil is removed. However, the soil has a high infiltration and water-holding capacity, and if it is properly worked future erosion forces can be controlled in a practical way on those areas not too seriously dissected or deeply washed.

In the southeast part of the farm, Durham fine sandy loam, Appling loam, and Cecil clay make up an area of 13 acres. The predominating slopes are not steep, falling into the B class, or from 3 to 7 percent. These soils are all subject to erosion, however, and because of improper cultural and cropping practices, sheet erosion is severe. The entire 13 acres has lost from 25 to 50 percent of the topsoil and parts have lost up to 75 percent of these productive layers. The other soils of the farm, including several alluvial soils along the north side, comprise some 6 acres. These alluvial soils are not very erodible.

Plans for Treatment

The major revisions in farm practices aimed at effective control of erosion on the cropland of the farm, briefly outlined here, are to be carried out over a period of 5 years.

The rotation of field 3, the largest of the farm, comprising 24 acres, will be lengthened and less cotton will be grown. Also the previous system of leaving one part idle or putting it through a rest period will be abolished, and more lespedeza and grain will be grown. The rotation will be lespedeza, cotton, oats—lespedeza, cotton, wheat.

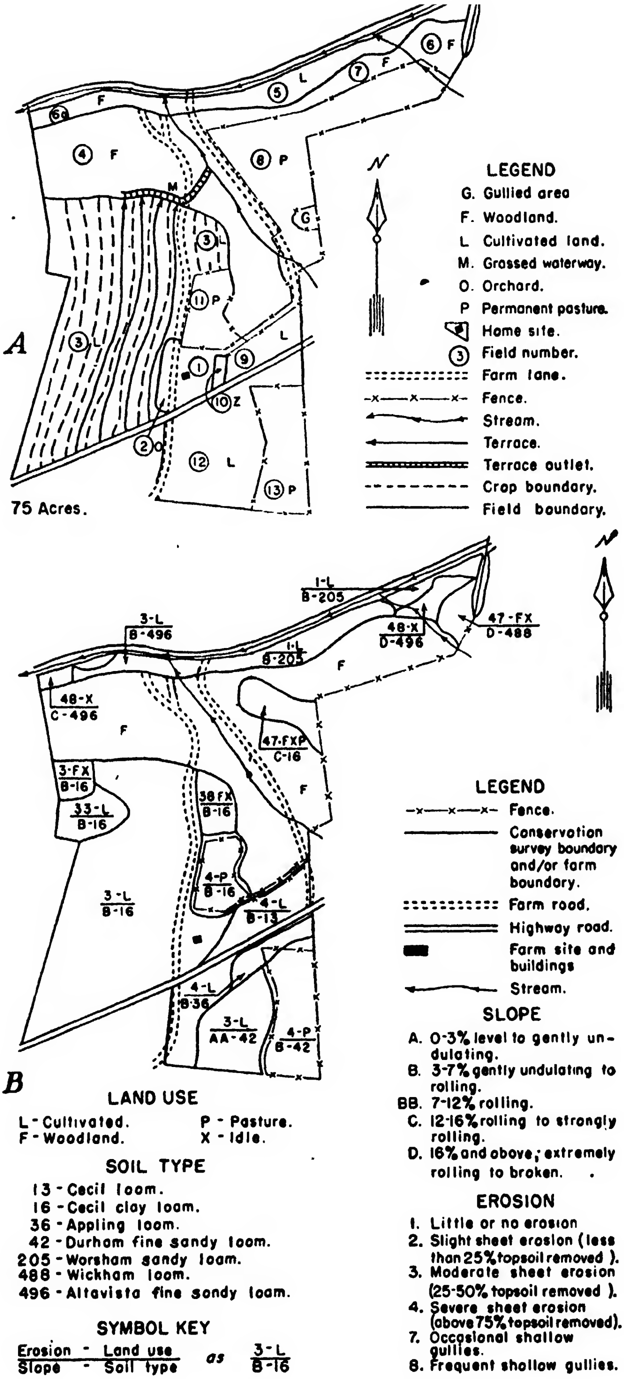

FIGURE 1.—*A*, Land-use map of the representative Cotton Belt farm at Providence N. C., illustrating erosion-control planning in the Southeast; *B*, conservation survey and soil map of the farm.

Four terraces will be constructed on the upper part of the field, spaced approximately 90 feet apart, and the field will be worked in strips with the terrace ridge in the middle of the strip.

Strip cropping alone, plus the revised rotation, will afford sufficient and practical protection on the lower part of the field, since the terraces on the upper part will reduce the run-off ordinarily traversing the entire distance of the slope. The entire field will be divided into nine strips, and no two adjacent strips will have cotton on them the same year. A small part of the field that lies east of the farm road will be divided into four strips and cropped in the same rotation as the major part of the field.

A terrace outlet will be constructed between the woodland area, field 4, and the terraced area, in field 3. It will be seeded to grass and set with shrubs and vines to give adequate vegetative cover. Stake-brush dams will be placed in the outlet to assist in the establishment of a protective grass cover.

Two very small areas at each end of field 5 (6 acres) are severely eroded and will be retired to woodland. This is practical, since they may be incorporated with the adjoining woodland area, fields 4 and 7. With the exception of these areas, the field has very little slope, and because of its high productivity will have a continuous corn rotation, with crimson clover seeded in each fall for winter cover protection and turned under in the spring as a green-manure crop.

Field 9 (2 acres) will have a 2-year rotation of wheat and lespedeza. Exclusion of clean-tilled crops will assist materially in erosion control on this field, and the lespedeza will build up this soil considerably.

Field 12 (8 acres) is on an area of Durham fine sandy loam, a rather smooth soil not subject to severe erosion except when improper practices are followed. This area, however, is severely eroded. It will be worked in strips of 90 to 110 feet in width, and a 2-year rotation of wheat and lespedeza will be followed. When the field is in lespedeza, only one cutting of hay will be removed and the subsequent crop will be plowed under as green manure. The area will be worked on the contour, but in view of the inappreciable degree of slope and the 2-year rotation, stripping is not recommended.

Pasture will assume increased importance on the farm when more livestock are added to the farm organization. Field 11 (2 acres) and field 13 (3 acres) will remain in permanent pasture to insure erosion control. However, since the livestock enterprises will be enlarged somewhat to keep the farm organization balanced, in keeping with the recommended agronomic phases of the program, 9 acres (field 8) will be cleared of brush and timber and developed as permanent pasture. There are some gullies in this field that will need treatment. They will be seeded, fertilized, and mulched, insuring adequate vegetative cover. Brush checks will be staked in these gullies to assist in establishment of the vegetal cover, and 500 pounds of a 3–8–3 fertilizer will be used on them. Approximately 80 rods of new, three-strand barbed-wire fence will be constructed on the west side of this field, and an equal amount of fence will be relocated from the south side of field 5 to the north side of field 8. In addition, about 20 rods of fencing will be necessary to protect the treated gully areas from grazing.

It is not uncommon to find woodland areas seriously abused and eroding. Field 4 (13 acres) is devoted to woodland and native brush cover. It includes low, wet areas and severely eroded former crop areas where the proper use is woodland. Exclusion of livestock from this field and attention to other proper woodland-management practices should aid the farmer materially in obtaining some increased return from this part of his farm. All woodland areas will be protected from fire. Field 6 (1½ acres) and 6a (½ acre) will be retired from cultivation and included with the larger area of woodland, fields 4 and 7. Some 2,600 loblolly pine seedlings will be planted on the 2 acres. A few gullied parts of the retired area need mulching, seeding, and fertilizing, to insure adequate protection. This will be done, and also 200 pounds of 3–8–3 fertilizer will be applied to stimulate revegetation of these critical areas.

Erosion-control plans are made for all parts of the farm. Areas 1, 2, and 10, comprising 3 acres, include the farm site, orchard, and truck patch. The orchard will be worked on the contour, and each year a winter cover crop of rye will be grown for erosion control. The truck patch will be cultivated on the contour, and applications of manure will be made annually to increase both fertility and the absorptive capacity of the soil.

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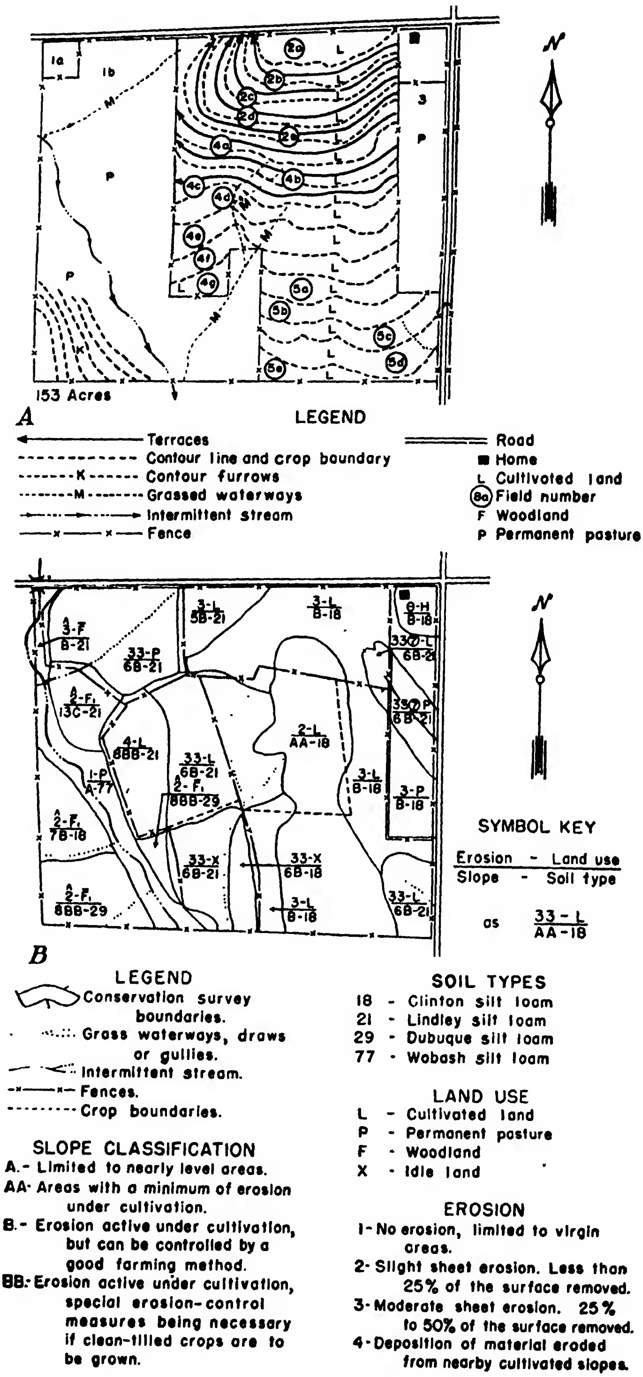

FIGURE 2.—*A*, Land-use map of the representative Corn Belt farm near Pecatonica, Ill., illustrating erosion-control planning in the Midwest; *B*, conservation survey and soil map of the farm.

Farm Near Pecatonica, Ill.

This 153-acre farm (fig. 2) is located in northern Illinois, where general livestock farming is assuming increased importance. The soils of this farm, except for 5 acres, are divided almost equally between two types—Clinton silt loam and Lindley silt loam. Both soil types are brownish yellow-gray silt loams developed on limestone and glacial till, respectively, and the original depth of the A horizon was approximately 10 to 16 inches in both cases. The slopes are undulating to rolling and vary from 2 to 12 percent. Considerable sheet erosion has taken place; on the majority of the land at least 25 to 50 percent of the original topsoil layers have been washed away (class 3 erosion). On part of the Clinton silt loam area erosion has not been so severe, falling within class 2 (not more than 25 percent of the original top layers of soil removed).

The erosion-control program outlined for this farm calls for approximately 55 percent of the total land area to be in crops. This is a somewhat lower percentage of cropland than is usual in some other parts of Illinois, in Iowa, and in Missouri. The plan, however, establishes an immediate program and one that will give assurance of the future fertility maintenance of comparable farms with gently rolling to undulating topography, erodible soils, and some appreciable soil losses to date.

In addition to serving in the capacity of erosion-control vegetation, many matured woody plants have definite importance in the farm economy. Field 1a (2 acres) will be retired from pasture to woodland and managed for future woodland purposes. This will provide adequate treatment for this small area, which has a relatively steep slope and has been severely damaged by erosion. A properly managed woodland will produce fence posts, lumber for repair of buildings, and other timber products, and will serve as a habitat for wildlife.

Forty-two rods of woven wire, 126 rods of barbed wire, and 50 fence posts will be used for construction of the fence necessary to protect this area from grazing. About 2,500 mixed hardwood seedlings will be set out in this 2-acre area.

Retirement of Eroded Cropland to Permanent Pasture

It is desirable in many cases to retire certain croplands that have eroded to an appreciable degree. Field 1b (57 acres) is designated for permanent pasture. Approximately 17 acres of this field will be retired from crops and seeded with a pasture-grass mixture. Oats will be used as the nurse crop. The old boundary fences will not be removed until the new pasture is ready for use. The following commodities and materials are necessary for use on this field: 50 bushels of oats (nurse crop), 425 pounds of mixed grass seed, 75 tons of agricultural limestone (to be used on new pasture areas), 300 fence posts, 220 rods of woven wire fencing, and 660 rods of barbed wire. Special attention will be given to the development of a good grass waterway at the north end of this pasture, where water comes from fields 2e and 4a and from the adjoining road ditch.

Seven acres of this pasture, in the southwest part, will be contour furrowed, to aid in holding more moisture, to obstruct surface run-off, and to reduce soil losses from erosion.

Pasture improvement where overgrazed.—Even permanent pastures are not free from erosion, especially where they have been improperly handled. Field 3 (8 acres) will continue in permanent pasture. This area has been overgrazed in the past and damaged somewhat by erosion along a draw in the middle. An application of 25 tons of agricultural limestone will be applied to aid in producing a heavier sod and to increase the carrying capacity of the pasture. Four tons of ground rock phosphate will also be applied to aid in rejuvenation of the pasture grasses.

Strip Cropping and Terraces

To break the slope.—Effective erosion-control practices and devices can be used that will not interfere with usual farm operations. Fields 2a (3.6 acres), 2b (3.9 acres), 2c (4 acres), 2d (4.2 acres), and 2e (4.3 acres) will be farmed on the contour in strips, with a predominant 5-year rotation of corn, oats (hay seeding), hay, corn, and oats (sweetclover seeding). The strips will be 100 to 120 feet wide, and the rotation will be followed for each strip so that no two adjacent strips have corn on them the same year.

The longer rotation established for this field will build up soil fertility, and the

strip-cropping practices, with alternate bands of close-growing and clean-tilled crops, will retard water run-off and decrease soil losses. Soil tests indicate that 60 tons of agricultural limestone will be needed for the field. Lime will be applied on each strip before seeding for hay.

A new fence will be constructed along the north side of this field to permit easy access to the pasture, field 1b, for which 130 fence posts, 96 rods of woven wire, and 288 rods of barbed wire will be needed.

Four broad-base Mangum terraces will be constructed in this field, in strips 2b, 2c, 2d, and 2e. They will empty into a grassed outlet which will be seeded along the west end of the lane bordering the north side of the field. These terraces will reduce run-off and assist in controlling sheet erosion.

To aid in gully control.—In many instances, practices and devices designed for erosion control on a specific field will assist in soil conservation farther down the slope. Fields 4a (6.5 acres), 4b (6.8 acres), 4c (7 acres), 4d (6.9 acres), 4e (7.3 acres), 4f (6.3 acres), and 4g (1.9 acres) will be operated on the contour in strips approximately 110 to 140 feet wide. Except for strip 4g, which is irregular because of the draw which will be fenced out and included in the pasture field, the cropping pattern will predominately follow a 6-year rotation of corn, corn, oats, and 3 years of alfalfa. This field is nearly level, and less than 25 percent of the topsoil has been removed; therefore, the rotation with 2 successive years of corn following 3 years of alfalfa can be followed without danger of speeding up erosion. The soil type on this field is predominantly Clinton silt loam, which, although subject to severe erosion when clean-tilled repeatedly, can be maintained from both a structural and fertility standpoint by following a good rotation, which will help keep up the organic content of the soil, and by utilizing practices which will prevent rapid water run-off.

Three broad-base Mangum terraces will be constructed on the upper part of this field in strips 4a, 4b, and 4c. These terraces will empty into the pasture field 1b. They will be constructed after the new seeding of pasture grass is well established on the east side of field 1b, where some cropland is to be retired. This disposal of excess run-off will reduce the amount of water going through the draw and potential gully which enters field 1b at the east end of strip 4g. Therefore, vegetation will be sufficient protection for the soil in this draw, and no structural work will be necessary.

Wider Strips and Shorter Rotations on More Nearly Level Areas

Erosion-control recommendations are made for different fields according to the seriousness of the problem involved. If erosion is not so serious, then the practices to be followed are not so rigid. Fields 5a (2.6 acres), 5b (4.4 acres), 5d (4.8 acres), and 5e (4.4 acres) will be worked as contour strips approximately 120 to 150 feet in width. Fourteen tons of agricultural limestone will be necessary on strips 5b and 5d, the first year of the rotation, since they are to be seeded to clover. A similar application will be made on each of the other strips before seeding them to clover later in the rotation. The rotation on this field may be shorter and include a higher percentage of clean-tilled crops, since it is almost level and past treatment has left it in a relatively high state of fertility. The rotation will be corn, oats (sweetclover), corn, oats, and hay.

General Comments

The established crop rotations will permit approximately 37 percent of the cropland to be in corn each year, 33 percent in grain, and 30 percent in hay. For some of the strips directly affected by terraces, it may be possible to use a shorter rotation and increase the clean-tilled crops somewhat. However, with more emphasis on soil-fertility maintenance and the enlargement of livestock enterprises, it is improbable that this farmer would need to reduce his proportion of hay and grains. From a long-time point of view, prices, regional shifts in emphasis on different enterprises, and other economic factors will guide him in amending his program.

Farm Near Winner, S. Dak.

This farm of 480 acres, located in Tripp County, S. Dak., is in the cash grain-livestock farming type area (fig. 3). The predominating soil type is Boyd clay

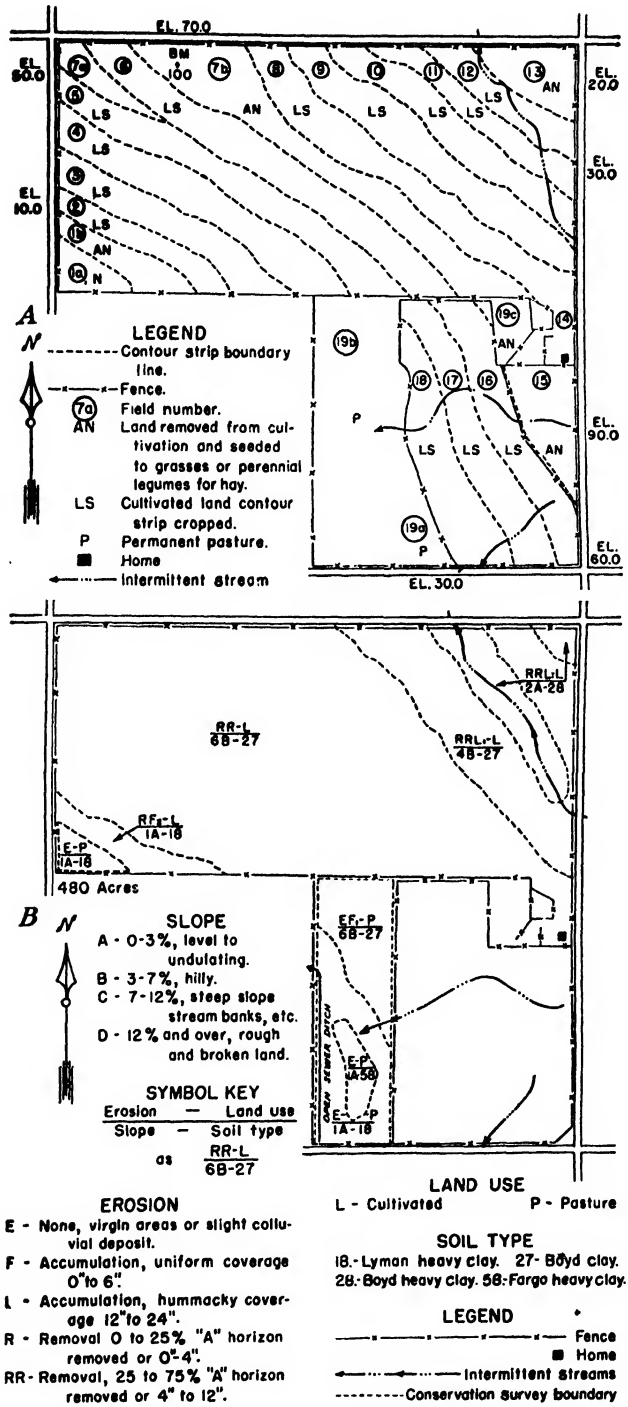

FIGURE 3—*A*, Land-use map of the representative Great Plains farm near Winner, S. Dak., illustrating erosion-control planning in that section: *B*, conservation survey and soil map of the farm

a heavy and somewhat impervious soil that is plastic when wet and breaks down easily into fine granulation when dry. In the latter condition, the soil is subject to severe wind erosion.

The land has a predominating slope of 4 to 6 percent, and has lost 25 to 75 percent of the topsoil, or 4 to 12 inches. The northeast 60 to 80 acres of the farm has a hummock coverage of from 12 to 24 inches.

Strip Cropping Planned

Strip cropping is effective in wind-erosion control when designed to afford sufficient cover on a particular area or on a nearby area so that the air currents will lose their destructive force. Strips laid approximately on the contour and in a northwest to southeast general direction will be established on 388 acres. The general width of the strips will be 275 to 300 feet. The rotation for the nearly regular width strips (fields 2 (17 acres), 3 (21 acres), 4 (26 acres), 5 (29 acres), 6 (32 acres), 8 (33 acres), 9 (26 acres), 10 (23 acres), 11 (19 acres), 12 (13 acres), 16 (20 acres), 17 (20 acres), and 18 (18 acres)) will be corn or sorghum, wheat, winter wheat, corn or sorghum, and wheat. The cropping plans are so arranged that no two adjacent strips will have corn on them the same year. Full advantage will be taken of the location of this farm, which is on the border between the winter wheat and spring wheat regions. Strips of spring wheat will alternate with strips of winter wheat, to insure coverage of one strip when the other has no crop.

The irregular areas between contour strips (fields 1b (16 acres), 7a (3 acres), 7b (28 acres), 13 (17 acres), 19a (9 acres), and 19c (8 acres)) will be seeded with a grass mixture, composed of 5 pounds of western wheatgrass, 1 pound of crested wheatgrass, 1 pound of bromegrass, 1 pound of sweetclover, and 1 pound of alfalfa. These areas and field 1a (9 acres), which now has a permanent cover, will remain in grass for a period of years, serving somewhat in the capacity of buffer strips, and will eventually be cut for hay. The alfalfa and sweetclover are included as supporting plants but will be crowded out after the first 2 or 3 years. When it becomes necessary to reseed one or more of the grass strips, new areas will be seeded in order to rotate grass over the entire cropland area during a period of years. Such a system provides for the maintenance of fibrous and binding material in all the cultivated land.

Field 15 (18 acres) will be retired from cultivation, and crested wheatgrass will be the main seed used to establish a permanent cover. For the immediate years, grass seed will be harvested and sold as a cash crop. Livestock enterprises will be developed in the future, and this field will be used as a permanent pasture area to make possible rotational grazing on fields 15, 19a, 19b (58 acres), and 19c. Field 19b has been overgrazed to some extent in the past, and careful consideration will be given to a reduced grazing program for this area until it is somewhat rejuvenated. The natural fertility of this area is such that no addition of commercial plant food materials will be necessary.

Tillage Practices and Management of Vegetative Cover

Proper tillage practices are very important as an aid in the establishment of vegetative cover sufficient to keep the soil from blowing. The lister will be used, preferably the basin lister, as the first tillage operation, on all bare and blowing areas. This will provide a temporary check to wind erosion, affording protection until establishment of the vegetative cover provided for in the rotation. Each tillage operation is planned so that the soil surface will be rough at all times when the land is not protected by a growing crop or by a crop residue. This will be accomplished, for example, by substituting the lister for smooth plowing, and by use of the duckfoot cultivator and spring-tooth harrow in place of the spike-tooth and smoothing harrow.

Feed crops will be cut high, and three to five rows of the crop will be left standing at regular intervals of 40 to 50 feet, to aid in reducing blowing hazards and to assist in holding snow. Grazing will be practiced on the crop areas only when sufficient cover has been established to protect the land from wind erosion. At no time will grazing be permitted up to the point where wind erosion can take place.

There are approximately 3 miles of fence-row drifts which will be leveled and border-planted to an erosion-resisting cover, such as sorghum and Sudan grass. The fences will not be rebuilt until the cropland area is well stabilized.

DRY FARMING has its own peculiar and difficult problems. This article tells about the nature of the soils in dry-land regions, shows why nitrogen is seldom a problem, and suggests measures to reduce wind erosion. Most of the article, however, is devoted to the problem of soil moisture, which is the limiting factor in production. The authors discuss means for increasing the available water supply, preventing water losses, and making the best use of what water there is by various tested practices.

Special Dry-Farming Problems

By O. R. Mathews *and* John S. Cole[1]

DRY-LAND FARMING, or dry farming, has many problems that are peculiarly its own. They are the direct results of a relatively low and uncertain rainfall that in the past has controlled the formation and character of the soil and now determines the conditions that farmers working the soil must face.

Dry farming in its broadest aspects is concerned with all phases of land use under semiarid conditions. Not only how to farm but how much to farm and whether to farm must be taken into consideration. Knowing the best way to grow wheat will not insure success in an area better adapted to grazing than to crop production. A section may be unsuited to intensive wheat production but well adapted to the growth of feed crops in conjunction with livestock production. However, on land suitable for arable agriculture, good farming methods may constitute the difference between success and failure.

Yields of crops that may be obtained over a long series of years, the extent to which annual yields may be modified or stabilized through cultural practices, and the response of different crops to each other are matters of fundamental importance in determining land use. Such information must cover a long period to serve as a secure basis for agricultural practices. Much of the present distress in the dry-land areas is the result of overexpansion of crop production in high-risk sections during a period of favorable years.

There are parts of the dry-land region that are suited to general mixed farming, other parts where one particular crop is so well adapted that the production of a large acreage of other crops is unjustified, and still other parts where yields of crops are so uncertain that farm-

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ing, if practiced at all, should be confined largely to the production of feed for livestock.

In the aggregate, the yields and dependability of the different crops that can be grown determine to a large extent the type of agriculture that should be followed, the size of farm necessary to produce a livelihood, and the proportion of the farm holding that should be devoted to arable agriculture.

DRY-LAND SOILS

The soils of the dry-land areas as a whole belong to the pedocalic group (soils with a zone of lime carbonate accumulation). Having developed under a light rainfall, they are unleached and have lost little of the elements of fertility present in the parent material. As a group they are rich in nitrogen and other elements needed for plant growth. The fertile soil extends to a depth unapproached by soils developed under humid conditions. Marbut (*239*)[2] draws the following comparison between forest and dry-land soils:

> The humid land forest soils are fertile, chemically so, when first cleared of forests; but the layer containing a high percentage of the constituents of fertility is very thin and is soon exhausted. The soils of the semiarid lands are entirely different in this respect. Not only is the percentage of what we call fertility constituents high, but the layer in which they are present is thick. Its thickness in feet is as great as the corresponding layer of the humid forest soils is in inches. It is so great that the world's experience up to the present time affords no basis for placing an estimate on the duration of the productivity of these lands.

Not all dry-land soils, however, are as deep as the typical soil described by Marbut. With the shallower soils fertility problems may soon assume importance.

The fertility of semiarid soils is their greatest asset, but it is also the cause of their greatest misuse. Crop returns are so abundant in years of ample rainfall that a succession of years with above-average precipitation has almost invariably led to an expansion in production that was entirely unjustified when yields that could be expected over a series of years were taken into consideration. This has frequently led to disaster when good periods have been followed by successive years with below-average precipitation.

In general, the fertility of dry-land soils is so great that the normally deficient precipitation is the controlling factor in crop production. In only a small proportion of years is the precipitation high enough or well enough distributed for fertility factors to limit the quantity of crop produced. Probably the greatest single dry-land farming problem is to adjust the entire farming system to the production that may be expected over a long period of years, so that years of failure may be endured.

THE NITRATE PROBLEM

The nitrate problem in dry-land farming differs from that in humid areas, where fertility frequently is the limiting factor in crop production. As a general rule, the nitrates released during the preparation of a seedbed and during the period of moisture conservation in dry-land areas are sufficient to produce as large a crop as the moisture is capable of maturing. Excess nitrates are frequently disastrous in dry

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

years, as they may cause a stimulation of growth that the moisture is incapable of maintaining to maturity. As a rule the addition of nitrate nitrogen, whether in the form of manure or commercial fertilizer, causes a vigorous early growth and a higher stover or straw growth than on unfertilized land. In many cases the water in the soil is incapable of maintaining this growth to maturity, and the yield of grain is lowered.

At Ardmore, S. Dak., 20 years of experiments with manured and unmanured fallow showed that the addition of manure increased grain yields in years of high precipitation, but decreased them in years of low precipitation. Instead of stabilizing yields, it made them more erratic. At North Platte, Nebr., 28 years of experiments with manures and green manures demonstrated that they increased the yields of straw and stover but decreased the yields of grain. At Goodwell, Okla., results at the Panhandle Experiment Station demonstrated that the presence of an above-average quantity of nitrate nitrogen had a depressing effect upon wheat yields. At Woodward, Okla., on a sandy soil probably as low in nitrogen as at any field station in the Great Plains, it was found that manures increased stover growth materially, but that crops fired more quickly in dry years. On the sandiest, lightest soils on the station the situation was most aggravated. These light soils were the most deficient in nitrogen and the most in need of fertility. Yet owing to the limited water-holding capacity of the soil (a result of soil type) crops were especially subject to injury during droughts when manures were applied.

As a whole it can be stated that in the Great Plains additions of nitrate nitrogen are not likely to effect much increase in yields of grain except in unusual seasons when water sufficient to maintain the excess growth is available.

In the intermountain dry-land areas of winter rainfall a somewhat different situation exists. There the lack of nitrate nitrogen may be a limiting factor in crop production. The reason lies in the fact that under continuous crop production the soil is frequently dry during the period of the year when temperature conditions are suitable for bacterial action. When moisture conditions are favorable, temperatures may be too low. Part of the value of fallow in that section lies in the fact that it provides moisture sufficient for bacterial action during a period of favorable temperature. This accumulates nitrate nitrogen, which is carried over to the next crop year. The results in average years are increased yields and improved quality. If the nitrogen is in excess in dry years, burning may result as in the Great Plains.

There has been a loss in total nitrogen in most dry-land soils since they were put under cultivation. The reduction was most rapid the first few years after the soil was broken, but has since continued at a gradually diminishing rate. The reduction in nitrogen has not yet become a controlling factor, however, and it is still a question on many soils whether the nitrogen content will become stabilized above or below the point where moisture is the controlling element in crop production. It may be safely stated, however, that at the present time few dry-land soils have reached a stage of nitrogen depletion. Maintenance or increase of the organic-matter content of the soil

through the application of manures or green manures will not pay for the cost where crops are grown for grain. Stover yields may be increased enough to justify the added expense.

WIND AND WATER EROSION

The prevention of wind erosion is one of the ever-present problems in dry farming. Ever since crop production started in the semiarid sections there has been soil blowing. During periods of drought the situation is aggravated, and with extreme drought and the large areas of land now under cultivation, it has become a national problem.

Losses of soil from wind erosion have been enormous. In many cases uncontrolled soil blowing has removed more of the elements of fertility in a single season than would be removed in generations of cropping. Some shallow soils have been rendered unfit for further cultivation.

In much of the agricultural land of the Great Plains and of the Pacific Northwest, wind erosion is a factor that must always be guarded against but that is a serious hazard in only a few years. In some sections and on some soils, however, it is the controlling factor. It may determine what crops can be grown, the practices that may be used, and in some cases whether the land should be farmed at all. For example, some sandy land that cannot be safely planted to wheat can be planted to sorghums without danger of serious blowing if the sorghum stover is allowed to remain standing. Some soils that cannot be fallowed safely in large blocks can be handled without undue risk if the fallowed and cropped land are arranged in alternating strips.

The best control over wind erosion is by preventing the soil from reaching a condition that permits it. Soils covered with a crop, with a crop residue, or with clods are in condition to resist wind action. Ridged soils likewise check soil drifting.

Tillage to conserve moisture does not always fit in with wind-erosion prevention. A soil covered with weeds will not blow, but neither will it reach a moisture condition suitable to the growth of a crop. If crops are to be grown, the necessary tillage must be given. The tillage, however, must be of a type that will maintain a surface as resistant as possible to erosion, while attaining the satisfactory moisture condition. This is not always wholly possible, but the use of implements that will leave crop residues and clods over the surface is one of the principal means of combating wind erosion.

One of the greatest dangers of wind erosion arises from crop failures, which leave the land free of protective residues. Too frequent failures may well indicate that the land cannot be safely farmed.

Preventive cultivation can be given to check soil blowing on land where movement has started. This is a recommended practice, but if proper tillage methods are used, the number of times that preventive cultivation is needed will be greatly lessened.

Water erosion is not so important a factor in dry-land sections as in more humid sections, although damage sometimes occurs. The greatest evil is the loss of water that may be vitally needed for crop production. For this reason the prevention of run-off is advocated to increase crop yields rather than to prevent soil loss, although it ac-

complishes both ends. The entire trend of cultivation has been to hold water where it falls until it penetrates the soil, rather than to lead it from the field by easy stages to prevent washing.

SOIL-MOISTURE PROBLEMS

Since water is generally the limiting factor in crop production, it follows that making the best use of the precipitation is the basic factor to be considered in a well-ordered farming system. This differs from the condition in humid areas where precipitation much above the average is likely to depress yields.

Owing perhaps to its relative newness as compared with agriculture in the more humid sections of the United States, dry-land farming has been a fertile field for theorists and opportunists. Most of the theories have been concerned with soil moisture. During the past 30 years numerous panaceas for the prevention of failure by drought have been proposed, accepted to a greater or less extent for a time, and finally discredited by most of those familiar with the problems. Among the theories or remedies widely accepted were the dust-mulch theory, which proposed that the top layer of soil be worked to form a dust mulch to break up capillary connection and prevent loss of moisture from the surface; the idea that exceedingly deep plowing or subsoiling would permit more water to enter the soil and to increase the zone where crop roots could develop freely; and the belief that water rises from the water table or deep subsoil by capillary movement.

Investigators soon discarded the maintenance of a dust mulch as a practice, because the finely pulverized surface increased run-off and was exceedingly subject to wind erosion. Deep plowing and subsoiling were discarded because of their expense, and because the rain that fell between harvest time and seeding time was often not sufficient to wet the loosened layer. The loose open soil favored loss by evaporation, and such deep tillage was more harmful than beneficial in dry years and ineffective in normal or wet years. It was also found that the depth of cultivation had little or no effect on root development, as root growth under most conditions fully occupied the moist soil area and was sufficient to exhaust the available water.

The fallacy of the rise of subsoil moisture from the water table or deep subsoil has been the hardest to dispel. Investigators soon found that movement of water upward except as carried by plant roots or as vapor was practically nonexistent in dry-land sections. They also found that the subsoil within the zone occupied by the roots of crop plants was normally dry at harvest time each year and remained dry except when wet from the surface, regardless of whether the subsoil beneath that zone was wet or dry. Yet there is a persistent belief that drought is caused by the exhaustion of subsoil moisture and the lowering of the water table. It seems not to be generally understood that in most of the dry-land areas there has never been a water table near enough to the surface to benefit annual crops even in favorable years.

At the present time a number of remedies that sound reasonable are being advanced for the prevention of crop failure caused by drought, but their economic and practical value is still to be determined.

The fundamental facts concerning soil moisture as a basic factor in the control of dry-land crop production as they are now understood

should be given consideration in any dry-land farming enterprise. A summary of these facts and their effects follows.

Crop Yields and Available Water Not Directly Proportional

The quantity of crop produced is not directly proportional to the quantity of water used. A considerable quantity of water is required before a measurable yield is produced. Any quantity less than this minimum results in failure. After the minimum requirement has been satisfied, yields, up to a certain point, appear to be proportional to the quantity of water above the minimum requirement.

A concrete example may be given to illustrate this point. Assume that in a certain section a precipitation of 10 inches represents the minimum requirement for wheat to produce grain. Under this condition a 9-inch precipitation would result in complete failure, but a precipitation of 12 inches would produce some grain. The difference in yield is not proportional to the amount of precipitation. It is the difference between no crop and a light crop. A precipitation of 14 inches would produce, not one-sixth more, but double the yield produced by a 12-inch precipitation, as there would be twice as much water above the minimum requirement.

This explains the value of comparatively small quantities of water in dry-land farming. The value of fallow and of other moisture-conserving practices is all out of proportion to the quantity of water stored compared to the total quantity required for crop production. This is because the additional water contributed is generally water above the minimum requirement. Over the Great Plains as a whole the value of 1 inch of conserved water is from 3 to 4 bushels of wheat per acre, provided the precipitation is sufficient to meet minimum requirements. At most places a difference in water content at seeding time can be translated directly into a difference in bushels of yield.

In parts of the winter wheat area the depth to which the soil is wet at seeding time (an expression of the available water stored in the soil) is so important that it serves as a basis for predicting at that time the order of yield that is likely to be obtained. This is probably because the rain that falls between seeding and harvest time is so often near the minimum quantity necessary to produce a crop that the quantity in storage at seeding time is the most important factor in determining the ultimate yield.

Precipitation Sole Water Supply

Except in certain lands along streams the only source of moisture for crop production is precipitation. This would appear to be too evident to require emphasis, but it is a fact that many persons still believe there are magic formulas for growing crops from sources of water other than precipitation. Along watercourses, however, water may be near enough to the surface to be reached by deep-rooted perennial crops such as alfalfa.

Soil Normally Dry at Harvest Time

Small-grain crops normally use before harvest time all the water in the soil that is available to them, leaving the soil dry, although in an occasional wet year there may be some carry-over of moisture.

Composite results for all years of record for all the dry-land filed experimental stations in the Great Plains, numbering about 20, show that land where small-grain crops were grown was dry at or before harvest time in fully 90 percent of the years.

This fundamental fact shows why tillage of small-grain stubble immediately after harvest has been so ineffective in the northern portion of the Great Plains. The possible benefit from such cultivation lay in preventing the loss through weeds of precipitation that fell between harvest and freezing. Since this period is short and precipitation during it is low, such loss is small in comparison with the moisture gained during the winter from snow held by undisturbed stubble. In the southern section of the Great Plains, on the other hand, small-grain crops are harvested early, and there is a long period between harvest and freezing during which the moisture from rains may be lost through weed growth. Cultivation after harvest in this area is often highly effective—but it is effective because it destroys weeds and helps the soil to absorb and hold rains that fall after harvest, not because it retains water already in the soil.

In more humid areas, cultivation after harvest may be useful in holding moisture already in the soil. Under dry-land crop production this is seldom the case. A definite knowledge of the purpose of cultivation after harvest should be a guide in determining under what conditions it should be practiced.

Means of Increasing Available Water

The quantity of water available to a particular crop may be augmented to some extent by growing it after a crop that does not exhaust the water supply of the soil to the same extent. It may also be augmented by reducing or eliminating crop production in one year to provide moisture for the next, as by growing corn or sorghums in very wide rows or by summer fallowing.

Water-Conserving Crops

In the northern portion of the Great Plains dry-land area, the carry-over in cornland of moisture available to small grain is reflected in higher yields following corn than following small grains. In the southern part of the Great Plains, there is a similar carry-over of moisture following corn, but early preparation of small-grain stubble frequently stores water equal to or greater than the carry-over on corn ground. Consequently the carry-over does not result in a materially increased yield of grain crops following corn.

Sorghums are another crop that may leave a carry-over of water. In the northern part of the Great Plains frost ends their growth about the time corn is harvested. Consequently yields of grain following sorghums are likely to equal or nearly equal yields of grain following corn. Farther south, most sorghums grow for a long period in the fall after small grains and corn are harvested, and they are still using moisture when land on which small grains or corn was grown may be storing it. Consequently, although sorghum does not usually reduce the moisture content of the soil to so low a point as do grain crops, sorghum land usually contains less moisture in the late fall than cornland or small-grain stubble land. This is reflected in a low yield of

grain crops following sorghum. The carry-over on sorghum land, moreover, is generally smaller than on cornland, because sorghums live and continue growth under conditions which cause corn to fire and cease growth.

Much of the value of the different row crops in dry-farming rotations lies in the reserve of moisture available to grain crops that they leave in the soil.

Wide Spacing

In the central and southern Great Plains, wide spacing of corn and sorghum to carry over moisture to supplement the next year's precipitation is being widely advocated, and has been the object of considerable experimental study. Little of this work has been long enough continued to permit positive statements, but certain trends are evident.

The results at Akron, Colo., of growing corn in rows twice the usual distance apart in comparison with rows of regular width and following each with winter wheat indicated an increase in the yields of the wheat, but this increase was obtained at the expense of a decrease of nearly 2 bushels per acre in the yield of corn grown in the wider spaced rows for each bushel of increase in the yield of wheat following it. The surety of corn production in dry years was not greatly increased by growing it in double-width rows. The yields of wheat following good yields of corn were higher on the double-spaced rows. When corn was badly injured by drought, the yields of wheat following it were little higher where the rows were double spaced than where they had the standard spacing.

Results with grain sorghums are more favorable to double spacing, chiefly because the grain yield of sorghums in double-width rows is nearly as high as in regularly spaced rows. When the sorghum does not suffer too severely from drought, the yields of wheat the following year are generally higher where the sorghum is double spaced. When the sorghum fails or nearly fails because of drought, double spacing the rows has little effect on the following yields of wheat. In drought years both corn and sorghum in double-width rows are able to exhaust all the available water from the soil, and the method provides no carry-over of water beyond that provided by planting in rows with the ordinary spacing.

From the experimental results that have been obtained, it appears evident that if the effect of a partial fallow is desired, the rows of cultivated crops must be spaced more than double the distance between regular-width rows, preferably a rod or more. Such widely spaced plantings are intended primarily to provide a condition of partial fallow, and at the same time grow a crop that may not be so valuable in itself but the residue of which should help in checking wind erosion. Its value will be chiefly in the extent to which it accomplishes this purpose. Experimental results on these very wide spacings are still too meager to afford a sound basis for recommendation for agricultural practice.

Fallowing

The greatest supply of moisture can be carried over from one year to the next by means of a summer fallow, which sacrifices one crop to

store moisture for the next. It provides a reserve of moisture unequaled in land that has grown a crop.

The most common method of handling fallow is to permit the stubble from a crop to stand over winter, to plow in the spring before weeds have removed much water, and to keep the land free from weeds but in a condition to absorb rains during the summer. In the Great Plains little advantage is gained by plowing early in the spring. The double purpose of holding water already in the soil and absorbing water from rains is best served by plowing when weeds are well started but are not using water rapidly, usually from May 15 to early in June, and thus leaving the land cloddy during the periods of heaviest rains in late May and all of June. Plowing as late as it can be done without serious loss of moisture is desirable, because it reduces the number of cultivations needed to keep the land free from weeds during the summer. Too long a delay, however, results in loss of water by weeds and a decreased efficiency of fallow.

In the Pacific Northwest, under winter rainfall, absorption of water during the summer is a factor of little importance. Conserving during the summer water that is already in the soil is the chief function of fallow. Consequently plowing is done there early in the spring to prevent loss of water by weeds and to avoid the loss of moisture incurred when plowing land in hot weather.

In recent years the prevalence of soil blowing has brought the plowless fallow into wide use. The land is not plowed, but is worked with a duckfoot cultivator or some other implement that destroys weeds without turning under the stubble. The exposed stubble helps prevent wind erosion during the winter months. Plowless fallow generally requires a greater number of cultivations than plowed fallow, but none of the operations is as expensive as plowing.

The lister, sometimes used on the contour, often replaces the plow for the initial operation on fallowed land. Regardless of the implements that may be used, the principles underlying the cultivation of fallow remain the same. They are the prevention of loss of water by weed growth and the maintenance at the same time of a surface condition resistant to run-off and to wind erosion.

Even on summer-fallowed land, however, it is possible to hold over only a comparatively small portion of the year's precipitation. So much water is lost by the drying of the surface soil following rains that comparatively little is available for deeper penetration. In the Great Plains it has been possible, on the average, to store only 20 to 25 percent of the precipitation. This is owing to the fact that most of the precipitation falls during the season when air and soil temperatures are high and humidity is low, conditions favoring a heavy loss by evaporation. In the intermountain regions, where much of the precipitation occurs in the late fall or winter, it is possible to hold a larger proportion of it in fallowed land.

Losses by evaporation are confined largely to the surface layer of soil, but crops remove water that is stored beyond the reach of surface evaporation. Consequently more water will be conserved in fallowed land than on land with a crop, no matter how thin the stand of crop may be.

The results of the carry-over of moisture are shown in the greater

surety and increased yields of crops on fallowed land. The value of fallow in any given section lies in the extent to which it increases yields above those obtained through other methods of cultivation and reduces failures. Yields must be materially increased for fallowing to be an economic practice, as no return is received from the portion of the land that is being fallowed.

In portions of the dry-farming regions grain crops, particularly winter wheat, are so outstandingly productive on fallowed land that the inclusion of a large amount of fallow in the farming system is sound practice. In other portions, yields on fallowed land are considerably less than double the yields on cropped land, but the inclusion of a limited acreage of fallow may be valuable as a means of controlling weeds and as an insurance against total failure.

The extent to which fallow can increase yields is largely limited by the quantity of water it holds within the reach of crop roots beyond that held by other methods of tillage. Fallowing or any other method of conserving moisture for the next year is of little or no value on very sandy land, shallow soils, or land too heavy to absorb and hold material quantities of water within the reach of crop roots.

Preventable Water Losses

The controllable sources of water loss are run-off and dissipation by weeds. The extent to which losses from these two causes may be reduced represents the limit to which the water available to crops may be increased by ordinary means.

Run-off occurs during heavy or torrential rains in most dry-land areas. The actual quantities of water lost by run-off have been determined at relatively few points. It is recognized, however, that losses by run-off are an important factor in most sections and on most soils. The more torrential the rains, the greater the losses by run-off are likely to be. In the northern Great Plains, water from melting snow running off from a frozen soil is an additional source of loss.

The rate of infiltration of water into a firm soil is definitely fixed by the soil type. It follows that if the precipitation rate exceeds the infiltration rate, there will be run-off unless the water is trapped on or near the surface. In some sections the trapping space provided by a loose, rough surface is sufficient to hold all water from ordinary rains. In all sections it is a material help. At Havre, Mont., it is said that there has been no run-off from properly maintained fallow in 20 years. In many other locations there has been run-off, despite the use of good cultural practices.

The fact that water needed for crop growth is lost through run-off has led, in recent years, to special practices for trapping water on the surface. Among those that may be mentioned are use of the basin lister, an implement that forms dams in lister furrows; contour listing and other contour cultivation; and level terracing. All these practices are designed to and do hold water that might otherwise be lost by run-off. Their value is in proportion to the quantity of water held at points where it can be used for crop production above quantities that may be held by ordinary good cultivation. At the present time it appears likely that the greatest usefulness of the basin lister and contour cultivation will be found in the production of row crops and

the maintenance of fallows. Their usefulness in small-grain production is limited by the fact that land occupied by a small-grain crop or stubble is less subject to heavy loss by run-off during the greater portion of the year.

Avoiding losses of water by run-off is one of the few practicable means of increasing the quantity of water for crop use. In very dry years, it cannot be expected to conserve enough water to insure crop yields, as in such years there may be little or no run-off. In most years it should be of value, although there is the possibility that it may have a depressing influence in very wet years.

Destroying competing weed growth is a practicable means of increasing the supply of water available to crops. Weeds use water very rapidly after they have made a substantial growth. As the total quantity of water available is not often sufficient to produce maximum crops, its reduction by weeds can result only in decreased yields. The destruction of weed growth increases crop production. There is a practical limit, however, to the effort that can be expended on the destruction of weeds, as the cost must be less than the value of the increased yield.

Efficiency of Water Use by Dry-Land Crops

Crops under dry-land conditions are not ordinarily more efficient in the use of water than the same crops grown under more humid conditions. On the contrary, more water frequently is required to produce a unit of dry matter, as the humidity is usually low and water loss by transpiration is high. Crops best adapted to dry land are those that make their maximum growth when climatic conditions are not too severe and the best use can be made of the limited water supply. Varieties of grains that make their maximum growth before the hottest part of the summer are generally most productive, although in an occasional wet year later maturing varieties may do better. More efficient use of moisture is probably the reason why winter wheat has generally displaced spring wheat in the area where both can be grown. Winter wheat is usually mature before the hottest part of the summer, whereas spring wheat, being somewhat later, most frequently completes its development under much more severe conditions of temperature and transpiration. Sorghums are particularly adapted to the southern dry-land section, because their growth requirements conform to the precipitation of the section. Their periods of greatest need for water come in June, for starting them and carrying them through their early growth period, and in August, for heading. Precipitation in these two months is normally higher than in July. Sorghums complete their growth in September and October when temperatures are moderate. They are also able to suspend growth and reduce transpiration during periods of stress, and to resume growth upon the return of favorable conditions, conforming to the water supply that may be available.

With these basic facts concerning soil moisture in mind, it is possible to perform cultural operations with a definite idea of what they may accomplish, and to adopt farming practices that are suitable to the section and the soil. The most that may be accomplished is to make the best use of the precipitation and of the stored water. No miracle

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is going to produce a crop without the use of a considerable quantity of water.

TILLAGE AND ROTATION PRACTICES

It will be apparent from the preceding that tillage and rotation practices are closely concerned with the soil-moisture problem. The control over crop production by tillage is small in comparison with the control effected by precipitation, but the quantity of precipitation is not subject to change through human agencies. Hence it is important that the measure of control that can be obtained through tillage practices be exercised.

Tillage may be divided roughly into two divisions: (1) Tillage in preparation for a crop, and (2) tillage during the life of a crop.

Tillage practices in preparation for a crop should create a moisture and nitrate condition favorable to growth and maintain a surface condition resistant to wind erosion. Such practices must be necessarily those that reduce or prevent run-off and that destroy competing plant growth. The kind of tillage called for depends upon the section and the crop grown. In the wetter section of the southern Great Plains early working of wheatland after harvest is an important means of storing water for the next wheat crop. Cultivation during the period between the harvesting of one wheat crop and the seeding of the next should be the amount necessary to control weed and volunteer wheat growth and to maintain a surface sufficiently open to permit ready penetration of water and cloddy enough to resist wind action. The use of implements that leave the residue of the previous wheat crop on the surface is desirable, as this assists in preventing run-off and checking wind erosion. In the nothern portion of the Great Plains the snow held by stubble is an important source of water, and letting the stubble stand over winter is a moisture-conserving practice. Cultivation can be delayed until spring. In portions of the Plains neither of these methods conserves enough moisture to reduce greatly the risk in continuous grain production. Where this is the case, and the soil type is suitable, fallowing a portion of the land is desirable in order to provide by tillage enough moisture to give a reasonable assurance of producing a crop.

With all cultivation, one principle should be the maintenance of a surface condition that encourages water penetration. Whether this will be in the form of any of the varied types of cultivated surfaces left by the several cultural implements or by an undisturbed stubble depends on the location and on the type of precipitation.

Another principle of cultivation should be the destruction of competing weed growth. This is important when weeds are removing stored water. Such cultivation should be with implements that do a thorough job of weed killing while leaving the surface in condition to absorb water and to prevent blowing.

The number of tillage operations should be the least that will accomplish the desired purpose. Too much cultivation breaks down the cloddy structure of the soil, destroys crop residues, leaves a surface that favors run-off and wind erosion, and increases costs.

The fact that dry-land farming is carried on on extensive areas with crops of relatively low acre value makes it imperative that the costs

be held down. The proper choice of implements and of times to perform the needed operations is the best means of accomplishing this object.

Tillage of growing crops under dry-land conditions may be considered as having one main purpose, that of destroying weeds. If cultivation sufficient to accomplish this purpose is given, no additional cultivation for the maintenance of a surface mulch is needed or desirable.

Crop rotations under dry-land farming have some basic differences from rotations for more humid areas. The maintenance of soil fertility is important but not nearly so immediately important as other factors.

In selecting crops and assigning them a place in the rotation more stress must be placed on their soil-moisture relations than on their effect on the soil fertility. Considerable stress must also be placed on the vegetative cover maintained at critical periods of the year, as this affects moisture conservaton and wind erosion, and on the amount and distribution of labor required under any particular system.

Limitations in the possibilities of crop rotations are (1) the number of crops that are adapted, (2) the effect of the adapted crops on each other, and (3) the type of farming practiced.

The number of crops whose net value per acre is somewhat near the same is small in comparison with humid areas. Where there are several, a rotation can be easily planned. Where one crop is outstandingly more productive or more valuable than any other crop, a rotation involving relatively large acreages of other crops finds little favor. For example, in portions of central Kansas winter wheat is a comparatively sure crop and is so outstandingly more valuable than other crops that every acre of cropped land not devoted to it means a loss of revenue. Under such conditions, the growth of other crops is largely limited to the needs for feed for the livestock maintained on the farm. In such an area, however, the effect of rotation need not be altogether lost. Hallsted (*139*) found at Hays, Kans., that a rotation of 3 years of wheat and 1 year of fallow was as productive as planting all the land to wheat every year on early plowed land. In addition, it provided a means of combating noxious weeds and distributing the yield more uniformly from year to year. The use of fallow had the effect of reducing the total yield in years of high production and increasing it in years of low production.

In some sandy soils sorghums are grown to the almost complete exclusion of other crops. Under such conditions some of the effects of rotation may be obtained by planting strips of legumes between strips of sorghums.

As a rule rotations for dry-land farming can be made comparatively simple. In fact, the limited number of crops that can be grown in many sections makes this necessary.

The use of crops in rotations depends upon their effect on each other. In the Great Plains corn and small grain work admirably together, because corn ground usually leaves a residue of moisture available to small grain. A further advantage is that the growth of the two types of crops affords a good distribution of labor. Where corn and small grain can be successfully grown, these form the back-

bone of rotation practice. The two crops are well adapted to rotations for farming systems where livestock production is carried on in conjunction with grain farming.

In the southern Great Plains sorghum and winter wheat do not fit in well together. The sorghum leaves the ground too dry for fall-sown grain. Where sorghum, small grains, and fallow are all adapted, the sorghum land can be fallowed, and the severe reduction in small-grain yield thus avoided. In the north, on the other hand, sorgos and spring grains are admirably fitted to follow each other.

Sod crops are considered a fundamental part of the rotation in many humid sections, but in dry-land farming they have not won a recognized place. The inclusion of sod crops in short rotations has not been a success. Establishing a stand of grasses is often too expensive unless it is to be left for more than 2 or 3 years. Further, while the long-time effect of a grass crop may be good, its effect on the crop immediately following is generally bad, because it leaves the soil exceedingly dry. In deferred rotations, where the grass is allowed to stand for a longer period, and a longer period intervenes between grass crops, such crops may be found better adapted. Information is still too scanty, however, to justify definite recommendations.

In the intermountain region the available crops are even more limited than in the Great Plains. In the strictly dry-farming areas alternate fallow and crop are essential for profitable yields. A simple rotation of fallow and wheat is the best for all conditions. Field peas, barley, oats, or rye may be used to advantage in limited amounts, but only with due consideration of the principles previously outlined.

The rotation must depend to a large extent upon the farming system. A system depending largely upon grain production for income can include only relatively small quantities of feed crops, as these are generally not profitable unless fed on the place. A mixed farming system consisting largely of livestock production must involve a greater use of feed crops and a lesser use of grain or cash crops.

With all crop rotations, an effort should be made to select crops and practices that leave the ground in condition to blow as little as possible.

Dry-land crops are grown on an extensive basis and arranging them in rotations and using methods that reduce the amount of labor without reducing the yields proportionately are effective means of increasing the farm income.

IRRIGATION in the United States began with the Indians in the Southwest before the coming of the white man. The Mormons in Utah were pioneers in establishing community irrigation projects. Later developments led to many forms of organization, out of which have come complex financial and legal problems in addition to the scientific problems that beset irrigation agriculture. This article gives a broad picture of the situation at the present time.

Irrigation in the United States

By Wells A. Hutchins, M. R. Lewis, *and* P. A. Ewing [1]

IRRIGATION was practiced in the southwestern part of the United States before the coming of the white men. Not only are there remains here of extensive irrigation works of unquestioned antiquity but the Spanish explorers found the Indians diverting and using water for irrigation in the Middle Rio Grande Valley and in a marsh near Acoma, N. Mex.; in the San Pedro and Santa Cruz Valleys, Ariz.; and in several other places. Taking care of the ditches was one of the important traditional community tasks in the Indian pueblos.

The Spanish settlers brought with them a considerable knowledge of and experience in irrigation institutions and practice, which they adapted to conditions they found in the Southwest. Out of the combination of Spanish and Indian methods grew what is called the Spanish-American community acequia. These organizations were widely established in New Mexico; and in portions of that State it appears that certain communities, which are using water today, have been under irrigation with little interruption since before the Spanish explorations. The Spaniards were likewise energetic in extending colonization and irrigation in Arizona, Texas, California, and Colorado, but in these States irrigation of Spanish origin now makes up only a small part of the present irrigation development.

The first Anglo-Saxons to practice irrigation on an extensive scale in the United States were the Mormon pioneers in the Great Basin, who in 1847 began the practice of utilizing water in crop production as a necessary means of livelihood. Without irrigation, Utah could never have become a great agricultural State. The irrigation enter-

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prises of the Mormons were community enterprises; and it is noteworthy that of the many lines of cooperative endeavor which were followed under church leadership in the development of Utah, irrigation is the only one which has remained consistently cooperative to the present day.

The Mormons extended their colonization activities into neighboring States, notably Arizona, Colorado, Idaho, Nevada, and New Mexico, and their irrigation institutions and practices went along with them. Independently of the Mormon development, the irrigation communities of northeastern Colorado came to be established, beginning with the Greeley Colony in 1870, and on the Cache la Poudre and South Platte Rivers these people worked out by trial and error and costly litigation a set of legal principles affecting water rights that have had an important bearing upon the body of water-right law in the Western States. In southern California the physical and climatic features lent themselves to a type of development involving the subdivision and sale of land adapted to high-priced crops, with water rights in incorporated mutual companies attached to the land. In all three of these sections—Utah, eastern Colorado, and southern California—the mutual irrigation company proved well-adapted to the organization and operation of these essentially community systems, and it is still the outstanding irrigation organization in those areas.

Commercial irrigation—that is, providing irrigation service to water users for profit—was much in vogue during the seventies and eighties, but on the whole it was disappointing and often disastrous to the investors. This type of enterprise is now of minor importance. There are a number of public-utility irrigation companies in California, but few in other States. One result of the many failures in the early commercial development was the passage of the Carey Act. The enterprises constructed under the provisions of this act were essentially commercial undertakings, but they tied the water to the land, which generally had not been done before. They depended wholly upon private capital for financing the construction of systems eventually to be turned over to the water users, and many investors suffered loss.

The irrigation-district movement involved still another form of enterprise—essentially community, but public and involuntary, and depending upon private capital for construction financing. The district movement has had a spotted history. It began in 1887 and reached its peak during the years following the World War. District bonds have been the subject of much refinancing, both private and governmental. This type of organization predominates in the West.

As the opportunities for irrigation through easy and inexpensive methods of diversion of water gradually disappeared there came a need for larger enterprises and higher per-acre expenditures to develop them. The combination of a demand for developing the public lands of the United States and the need of Federal funds for the large undertakings led to the passage of the National Reclamation Act in 1902. The work done under this act has been extended to include reclamation of private as well as public lands. Of the total area irrigated in the United States, between 10 and 15 percent has been made possible by the Bureau of Reclamation.

Where extensive areas have been involved and settlement by diverse elements of population has come about, the economic complexities of a type of agriculture already unusual have multiplied far beyond those which marked the beginnings of irrigation farming in the United States. However, to a degree quite unappreciated by many persons, these involvements and complexities have not characterized the operations of families on the majority of the irrigated farms in the West, for the greater number of those farms receive their water supplies from individually or cooperatively owned systems, many of which were built by the farmers themselves without recourse to the financing operations necessary for large-scale community developments.

EXTENSION OF PUMPING

Nevertheless, other complexities have arisen to tax the ingenuity and resourcefulness of many irrigators. Some of the most important of these have arisen from the relatively recent development of pumping for irrigation, especially from wells. Of the 19,000,000 acres irrigated in the 19 Western States included in the last Federal irrigation census, nearly one-third—that is, more than 6,000,000 acres—received at least some pumped water, and as a result of the series of droughts occurring since 1930 many more pumping plants are operating in eastern and midwestern communities formerly little acquainted with either the need for such irrigation or the economic problems it has added to those they previously faced. Still to be met by some of these new pumping areas are the serious problems of depleted underground storage and increased lifts which now bother many of the older communities. Some of the older communities, ingeniously assisting nature through so-called water spreading, are able effectively to recharge their underground storages by diverting floods, otherwise wasting oceanward, into the gravel reservoirs from which the pumps are supplied; but these opportunities are not common, and the general problem of fitting withdrawals to the normal recharge is one of the major dilemmas which western irrigators have to add to the mechanical and financial problems of pumping. The legal features involved are most complex.

There still remains a field for reclamation by pumping where underground water is available in assured quantities and without excessive lifts; also by storage of surface waters in small reservoirs to provide additional supplies where irrigation is now being done, and to supplement dry-farming programs (fig. 1).

SUPPLEMENTAL IRRIGATION

In one sense almost all irrigation is supplemental since direct rainfall provides some part of the water supply in almost all areas. In the Eastern States and on the Pacific coast irrigation may supplement natural rainfall during periods of drought. In successful dry-land farming areas, irrigation of home gardens and forage crops for work stock and milk cows is often advantageous.

At high altitudes throughout the West and in most of the Great Plains livestock runs on native grass pastures or on the open range during most years and during much of the year. In most of these areas, however, it is essential that other winter feed and emergency

supplies be provided for use during extremely dry years. Often irrigation offers the only possible method of providing such insurance. The recent drought periods in the Great Plains region brought

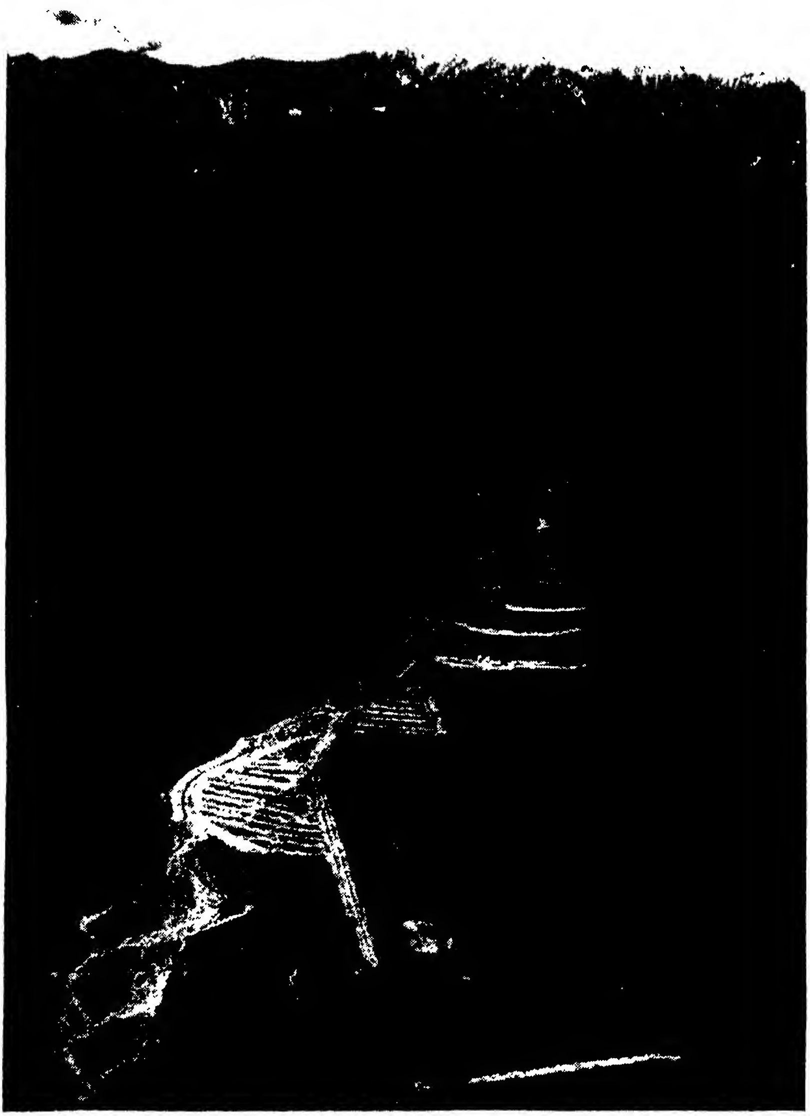

Figure 1.—Through use of rock and earth dams on the debris cones of streams where they come out of mountain valleys, a part of the floodwaters can be spread out to seep into underground reservoirs for future use in irrigation by pumping. Short, parallel, white lines at right angles to the stream show the location of walls.

very forcibly to the front the need for this type of supplemental irrigation.

Stabilization of agriculture in many parts of the United States could be aided greatly by irrigation of these three types: (1) Supplementing the natural precipitation during dry periods in normally humid areas; (2) watering gardens and small forage patches on dry-land farms; and (3) supplementing range livestock feed by growing winter and emergency forage crops.

It seems obvious that the more extensive irrigation developments undertaken in the future must be financed from public funds, costs to be shared by all who benefit from them whether they be on the land or far from it. Among other safeguards to be taken against the repetition of past disasters are the more careful classification of physically irrigable lands on the basis of probable productivity, and the more equitable assessment of costs against them on the basis of their varying possibilities. In making such classification greater thought must be given to economic considerations while not ignoring soil, water, and plant relationships.

LAND CLASSIFICATION AND IRRIGATION

Land classification is of special importance in irrigated areas for three reasons. (1) The requirements and possibilities of farm land are both peculiar to and higher under irrigation. (2) Almost universally the supply of water that can be economically made available for irrigation is insufficient for all available land, and therefore should be used only on the better lands. (3) The cost of providing irrigation water cannot be borne by poor land.

The classification of land for irrigation requires particular attention to three factors in addition to all those that apply to nonirrigated lands. The topography must be such that water may be economically transmitted to each farm and satisfactorily distributed over the fields. The soil must not contain excessive quantities of alkali salts. Because irrigation increases the water supply, special care should be used to ascertain that the natural drainage, particularly below ground, is adequate or that adequate artificial drainage can be provided at a reasonable cost.

Since with adequate irrigation soil moisture ceases to be the limiting factor in crop production and because of the higher costs of irrigation farming, irrigated lands should be of good quality, particularly with regard to depth, fertility, and workability. On the other hand, owing to the possibility of controlling moisture conditions by irrigation, certain soils, almost worthless because of unsatisfactory moisture characteristics under nonirrigation farming, may be highly productive with irrigation.

Index systems of rating soils, such as those devised by Storie, of California, and by Kellogg in North Dakota, because of their flexibility, give promise of being particularly useful in the planning of large-scale irrigation developments. However, without regard to what the Nation's future attitude shall be toward the extension of its irrigated areas, the present concern of the Department of Agriculture is principally with the problems of farmers already on irrigated farms.

IRRIGATION LAWS AND CUSTOMS

Whatever its source, water is now so valuable throughout the West that rights to its use in irrigation have an importance equal to and frequently exceeding that of titles to the land on which it is applied.

The common law doctrine of riparian rights to the waters of surface streams has been rejected as unsuited to physical conditions in the more arid Western States, and has been modified or restricted in application in most of the semiarid States, that is, those bordering the Pacific Ocean and those lying on the ninety-eighth meridian. In all the 19 Western States the doctrine of prior appropriation for beneficial use is in force, either exclusively or in conjunction with or subordinate to the underlying riparian doctrine. Water rights for only a small percentage of the lands irrigated from surface streams are based upon riparian ownership. The riparian doctrine has proved far less suited to the requirements of irrigation agriculture than has the appropriation doctrine, but the vesting of riparian rights in specific tracts of land has caused serious complications in various areas.

The recent increase in use of ground water for irrigation has been especially notable in California. Rights to percolating ground waters in that State are based upon the correlative doctrine, which allows owners of land overlying a common basin equal rights to the ground water. In some States such rights are based upon reasonable use; in others, upon absolute ownership of the water; and in still others, upon the doctrine of prior appropriation.

The laws governing rights to waters of surface streams are fairly well defined; however, there has been and still is a definite trend toward modifying the riparian doctrine, and it is now coming to be recognized that modifications in the strict appropriative doctrine are inevitable if the public interest is to be properly served. The whole body of ground-water law is in a state of flux, and much remains to be done in harmonizing the rights to ground waters with those to waters of surface streams with which such ground waters are physically connected. It is a foregone conclusion that in many important areas fundamental adjustments in principles of ground-water laws will be required if efficient utilization of water resources is to be brought about.

The Department of Agriculture has become increasingly concerned with questions of water rights. Various activities of the Department have to do with the diversion and use of water both by Federal agencies and by private individuals. A comprehensive study of laws governing water rights in the Western States is now under way, with particular reference to the rights and responsibilities of the Federal Government. In the meantime the Department is cooperating with State agencies in several cases in efforts to improve State water laws.

SNOW SURVEYS

Of no less importance than the matter of security in his possession of a "right" to water is the irrigation farmer's concern over its availability and effective use. Since the irrigated regions in the Western States are dependent to a large degree on water that accumulates as snow in the mountains there has long been a desire among irrigation

men to determine in advance the probable supply of water from this source for the ensuing season (fig. 2).

Preliminary efforts to supply such information through snow surveys finally resulted a few years ago in the establishment by the Department and the irrigation States of a snow-survey project which now provides regular seasonal reports on the prospects for irrigation water from various watersheds. The facts are obtained by actual measurement of snow samples taken along snow "courses" carefully laid out on the various watersheds. The final report on the season's supply for irrigation and storage is issued about the first of April and enables the farmers and reservoir operators to so adjust their activities as to avoid loss of water, seed, and labor.

FIGURE 2.—Weighing a snow tube with its core of snow, obtained by thrusting the tube through the snow cover.

Preliminary information also is a factor in making possible maximum use of reservoirs in flood control since when snow supplies are large, reservoirs may be partially emptied and later refilled at the time of the big flow. In other cases reports may indicate the wisdom of retaining all the inflow. Consideration of the snow-survey reports in connection with information on stream flow makes possible accurate prediction of the monthly as well as the seasonal water supply.

DUTY OF WATER

To obtain the greatest benefit from water the farmer must know the economic duty of water for the crops he wants to raise. Thus problems in scientific agronomy are added to the financial, legal, and ofttimes mechanical interests involved peculiarly in irrigation farming.

The term "duty of water" means the depth or quantity of irrigation water required on the land to produce a crop. As the object of irrigation is to keep plants growing, an analysis of the duty of water should start with the water requirements of these plants. The quantity of water evaporated directly from the soil must be added to the direct water requirement of the crop itself. The sum, considered with relation to the yield of crops, is a quantity known as the evapo-transpiration ratio; that is, the number of pounds of water transpired and evaporated from the soil for each pound of dry matter in the crop produced.

To find the irrigation water needed, it is necessary to subtract from the water requirement based on the evapo-transpiration ratio, the water obtained from growing-season rain and from moisture stored in the soil at the beginning of the crop season.

Certain surface run-off and deep percolation losses are unavoidable in applying irrigation water. Adding these losses gives net or farm duty. Other losses, some unavoidable, occur between the natural stream or reservoir and the farmer's ditch. Adding these to the net or farm duty gives the gross or diversion duty.

By considering only unavoidable losses a more or less ideal duty of water is set up. In actual practice and in law, certain other factors must be included. Early in the administration and adjudication of water rights it became necessary to decide which losses were unavoidable and which avoidable, and courts and irrigation interests determined reasonable requirements.

Later, the conception of economic needs was added and the duty of water was considered as including the water required on the land to produce profitable crops, plus such losses on the farm and in transmission as it was not economically feasible to prevent. Another factor, the water which must be allowed to percolate through the irrigated soil to carry off excess soluble salts beyond the root zone, is now being considered.

Since water is the limiting factor in the development of the arid States, the public good must also be considered. In most of the arid States the legal conception of a water right is a right only to the beneficial use of water. Modern thinking tends toward limiting the uses to which private individuals may put either land or water. Here, therefore, are involved more complications by reason of the relationships between soil, plant, and water.

SOIL-WATER-PLANT RELATIONSHIPS

The soil is a storehouse of plant nutrients, a habitat for bacteria, an anchorage for plants, and a reservoir to hold water needed for plant growth. The irrigation farmer is primarily interested in how much that reservoir will hold and how the supply may be replenished.

The quantity of moisture any soil will hold, per unit of volume, depends chiefly upon the fineness of the particles and the quantity of organic matter. The finer the soil particles and the greater the proportion of organic matter, the more moisture will be held. It is true, however, that soil structure may be altered by treatment, while texture remains the same. The quantity of water held in well-drained

soil shortly after long-continued rains or heavy irrigation is known as the field capacity.

The wilting percentage is the quantity of water still remaining in the soil when plants can no longer get water rapidly enough to maintain growth. The difference between these two quantities is known as the available capacity of a soil.

Plants cease to grow at the maximum rate even before the moisture content of all the soil in the root zone is reduced to the actual wilting percentage. The point at which decreasing soil moisture will slow the growth of plants depends on various factors, including distribution of roots, climatic conditions, soil types, and, probably, kind of crop. The exact degree of soil dryness at which reduction in rate of growth of various crops becomes important has not yet been definitely established and is now the subject of much research.

If the approximate point at which the growth of a crop slows up, the field capacity, the depth of the major root zone, and the apparent density of the soil are known, the actual reservoir capacity can be determined. The rate at which crops extract water from the soil may be determined experimentally. From these two factors the time between irrigations and the quantity of water required at each application can be estimated. Another method has been recently developed for citrus crops. A slowing down of the rate of growth of the fruit indicates a depletion of the soil moisture and is a signal for irrigation.

If moisture in excess of the field capacity is applied, either the excess will percolate away uselessly out of the root zone or the soil will become waterlogged. Some waste is unavoidable, because the water must be used as a carrier, hence a little should be allowed to percolate away to prevent the gradual accumulation in surface soil of the soluble salts present in all natural water. If more water than is needed for this leaching of soluble salts passes below the root zone it is wasted so far as crops are concerned. In the absence of ground water, capillary movement in the soil is slow and limited and, in general, the roots must extend into moist soil rather than rely upon moisture rising to them by capillary action.

Crops produced on highly fertile soils will be larger than those produced with the same water supply on infertile soils. Otherwise, under the same climatic conditions, the soil type does not materially influence the water requirement of a crop; but it does influence the number of irrigations, the quantity of water used at each irrigation, and the method of applying water. The method of applying water is controlled by the rate at which water will sink into the soil, topography, water supply, and variety of crop.

The skill of the irrigator is a major factor in the results which may be obtained with the available water supply, which is nearly always insufficient for all the land that might be irrigated and is often a limiting factor on the lands actually in use. A skillful irrigator will endeavor to fill the soil within the root zone uniformly to field capacity with little waste either on or below the surface. Very heavy or very sandy soils and land with steep or irregular slopes require especial attention. Whenever possible lands are carefully leveled or smoothed and otherwise prepared for irrigation. On heavy, slightly pervious soils small streams are used whereas on sandy or highly permeable

soils streams as large as can be properly controlled without soil washing are required. On steep slopes the use of contour furrows, permanent grass cover, or terracing may help to prevent the erosion of soils by irrigation water.

Irrigation water is applied to the soil from overhead by sprinkling, on the surface by several types of flooding and furrows, or under the surface by subirrigation. Sprinkling in general requires a larger investment for equipment and entails considerable cost for power for pumping. Nevertheless on certain crops, partioularly garden truck, and on very permeable or uneven land the method is successfully and, in some areas, generally used.

On nearly level and gently sloping land the strip border method in which low dykes are built in parallel lines down the slope and the water flows down the intervening strips in thin sheets is most suitable for field crops. Row crops in general are irrigated by allowing the water to flow in small streams down small furrows between the rows. A modification of this method, called the corrugation method, is used for field crops on sloping lands and on soils that tend to crust.

Subirrigation can be used only under very special conditions and even then is subject to the danger of causing excessive concentrations of soluble salts.

PHYSICAL AND CHEMICAL CHANGES IN SOILS

Both deleterious and beneficial changes in the physical and chemical characteristics of the soil may be brought about by irrigation.

. If no water is allowed to percolate out of the root zone irrigation waters high in soluble salts may leave an accumulation of such salts in the surface soil. Even with ample percolation, irrigation waters low in calcium may cause an unfavorable physical condition of the soil. Under conditions of poor drainage the soil may become waterlogged, or toxic concentrations of alkali may be brought to the surface by capillary action.

When legumes are grown or green-manure crop residues are plowed under, irrigation may result in gains in soil nitrogen and organic matter. Irrigation water high in calcium and magnesium may improve the physical character of the soil by replacing sodium. With such water, highly alkaline soils may be reclaimed.

Certain types of hardpan are disintegrated by irrigation. Very sandy soils may be improved by the addition of fine silt carried in irrigation water.

RESEARCH AND IRRIGATION

Irrigation is one of those human activities carried on since time immemorial and into which formal research is a late comer. Since it was widely practiced when the Department of Agriculture and the agricultural experiment stations were organized, their first work in this field was of the survey type illustrated by early bulletins of the Office of Experiment Stations.

Field experiments followed in which times and amounts of irrigations were varied and the resulting yields compared. This type of work was done in Idaho and by State engineers in other western

States who needed information on the proper duty of water in the administration of water rights.

At about the same time the Utah and other agricultural experiment stations made similar but more detailed studies. In addition to measurements of the water applied and crop yields, determinations of soil moisture were made. This type of work has been continued and refined, and now climatological data, soil characteristics, and the responses of the crop to differences in soil moisture are observed and recorded in detail. Modern research in this field is illustrated by the cooperative work of the Bureaus of Agricultural Engineering and Plant Industry and different agricultural experiment stations, and the independent work of several stations.

Another example of irrigation research applied to specific problems of a group of agriculturists is the work of the experiment station of the Hawaiian Sugar Planters' Association.

While theoretical analyses of so complex a problem as that of soil-water-plant relationships must be checked at every step by experiment, an understanding of fundamentals is essential to further progress. Reports from the Utah and California Stations indicate such progress.

The construction and management of irrigation systems present a host of problems in addition to those directly associated with the use of irrigation water by crops. Problems of organization and the control of water have been studied and reported on by the Bureau of Agricultural Engineering.

Adequate design, construction, and operation of irrigation systems depend on accurate knowledge of the dynamics of flowing water and correct measurements of flowing streams. The Division of Irrigation has obtained valuable results from research in both these fields.

Irrigation water is stored in natural valleys, often behind earth dams, and is conveyed by earth ditches. Here, as well as in the application of irrigation water to the land, questions of the natural permeability of soil and methods of changing that permeability are paramount.

The most pressing problem of irrigation research is probably that of the concentration in surface soils of soluble salts derived from irrigation waters. The Department of Agriculture in cooperation with 11 Western States and the Territory of Hawaii has recently organized a regional laboratory to study this problem intensively.

Other vital problems of irrigation research include the economics of supplemental irrigation, soil-water-plant relationships, the practical problems of the efficient application of irrigation water on the farm, and the physics of soil moisture.

BY FAR *the largest number of failures in irrigation agriculture, according to this author, have been due to unfavorable conditions of soil, water supply, and drainage not realized in advance. Soil formed in a dry climate has peculiar characteristics. It is not enough merely to supply this soil with water; that viewpoint is likely to lead to mistakes. This article gives particular attention to the character of the soil solution, the quality of the irrigation water, and the necessity for continued research on problems that are as yet unsolved.*

Soil, Water Supply, and Soil Solution in Irrigation Agriculture

By C. S. Scofield [1]

MANY people have learned through sad experience that not all irrigated land "blooms as the rose" and that the productivity of some of it is relatively short lived. On the other hand, it is true that a great number of such developments are very successful and continue highly productive after many years or even centuries. In Egypt and elsewhere in north Africa, in the south half of China, and in the river basins tributary to the Persian Gulf, agriculture under irrigation has flourished throughout historic times. The causes of failure, where it has occurred, are not always clearly understood or fully agreed upon. Even in this country, where irrigation has been used extensively for less than 100 years, there are numerous instances of failure through declining crop yields as well as many other instances of long-sustained and continuing productivity. It seems clear that long-continued irrigation farming is practicable where conditions are favorable. If the causes of failure are ascertained and clearly understood, methods of avoiding it may be devised and used.

A review of the history of irrigation development in this country [2] shows that, while some failures may be assigned to unfavorable economic or social conditions and a few to ill-advised or inadequate engineering or overoptimistic promotion, by far the larger proportion have been due to unfavorable conditions of soil, water supply, and drainage, which were not realized before development was started. Inadequacy of information concerning these conditions or failure to

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[2] See Irrigation in the United States, p. 693.

use the information available has been the root of the trouble. In many instances, the areas of our irrigable lands are much larger than may be adequately served with our available supplies of irrigation water. The natural tendency has been to use the water on the land to which it could be most easily applied or to spread the water over more land than could be adequately served. Lack of knowledge as to essential soil characteristics that make for success or failure under irrigation has been conspicuous. Not less so has been the lack of information as to the quality of irrigation water, or the appreciation of the need for effective drainage. These are among the more important agronomic factors that lead to declining crop yields.

Irrigation is used as an aid in crop production on soils that are not adequately supplied with natural rainfall. It is not limited to arid regions. Periods of drought occur seasonally in areas having abundant annual rainfall, as for example in Florida during the winter and in the Pacific Northwest during the summer. One of the important functions of the soil is to serve as a reservoir to supply continuously the water required by crop plants. Its capacity as a reservoir is limited, however, and during periods of active crop growth it must be replenished from time to time either by rainfall or by irrigation. Many of the soil problems that arise in connection with irrigation relate directly to this function of the soil as a reservoir for water.

The subject of the soil as a reservoir for water to be used by crop plants has three major aspects: (1) Conditions that relate to the input of water; (2) the volume capacity of the soil as a water reservoir; and (3) the removal of harmful residues that naturally tend to accumulate in the soil reservoir with continued use. People who work with the soil, whether as farmers or as technologists, know it to be essentially dynamic. It is a complex of diverse organic and inorganic materials, continuously reacting physically and chemically, and of equally diverse living organisms whose normal processes of growth and of decomposition play an important part in the changes that occur. These changes affect not only the fertility of the soil but also its physical characteristics, including those that are involved in the absorption, conveyance, and retention of water.

The application of irrigation water in abundance to soils of arid regions may have consequences unsuspected by those engaged in developing projects and by farmers settling on the land. Our crop plants, with a few exceptions, require an aerated root zone. With an abundant water supply from either rainfall or irrigation this requirement can be met only by free subsoil drainage.[3] The lack of such drainage results in swamp conditions to which few crop plants are adapted. Drainage becomes even more important if the irrigation water contains relatively large quantities of dissolved salts. Where proper drainage is lacking these salts accumulate in the soil solution of the root zone to the detriment of growing plants and of the soil itself. Deficient subsoil drainage and resulting swamp conditions are made obvious with abundant rainfall and may thus be avoided or remedied in advance of use, but under arid conditions the drainage deficiency may not become apparent until after the land has been irrigated for some years.

[3] See Drainage in Arid Regions, p. 717.

SOILS FOR IRRIGATION

The ideal soil for irrigation is one of medium or fairly fine texture and of deep, mellow, open structure, allowing easy penetration of roots, air, and water, and having free drainage yet good water-holding capacity. This ideal combination of soil characteristics most often exists in the more recently deposited alluvial soils on the flood plains of streams or on alluvial fans. These soils make up large parts of some of our irrigated sections, especially in the Southwest. They are naturally not only highly productive but comparatively smooth or level and they lie in such a position that they may be rather easily supplied with irrigation water. Typical alluvial soils of the arid West are those of the Gila, Hanford, and Yolo series. Another essential feature of a soil for irrigation is that it be relatively free of harmful salts (alkali). This is not always true of alluvial soils, especially after irrigation has been started on adjacent higher lands. Alluvial soils are variously and irregularly stratified and variable in texture and in places contain layers of sand, gravel, or clay. This lack of uniformity of texture and stratification presents difficulties to the soil specialist in classification and mapping of soils. Its importance is now fully recognized, although this has not always been true.

The soils of upland areas are developed from older alluvial, lake-laid, wind-laid, or loessial (fine wind-borne) deposits, or from an underlying bedrock. Large areas of these older soils are under irrigation in places. Soils developed from loess are generally very desirable. Such soils (Portneuf series) cover the greater part of the Twin Falls section in southern Idaho. The upland soils commonly have more definite profiles, greater uniformity of texture, and less variable stratification than alluvial soils. They are likely to have better surface drainage and to be comparatively free from soluble salts. Many areas are coarse-textured, sandy, gravelly, or stony and have lower water-holding capacity, lower content of organic matter and nitrogen, and lower availability of phosphorus than the alluvial soils. Many areas are underlain by claypans, hardpans, or bedrock at shallow depth. All in all, most upland soils are naturally less productive than most alluvial soils, but the former are less subject to damage by water-logging and concentration of salts.

Neither very sandy soils nor heavy clays are generally desirable for development under irrigation. The sandy soils do not hold sufficient water, are relatively infertile, and have a tendency to blow; the clays do not drain well, are hard to plow and cultivate, and are less productive under average farming practices than medium-textured soils. The soils of medium texture—fine sandy loams, very fine sandy loams, loams, silt loams, clay loams, and silty clay loams—are commonly most productive and most desirable for development under irrigation.

The plans for an irrigation enterprise should include the survey of the soils and classification of the lands[4] as well as an investigation of the available irrigation water and the means of conserving it and conveying it to the land. Furthermore, experience has shown that after irrigation has become established, reexaminations of the soil

[4] This subject is more fully discussed in the articles Soil Maps and Their Use, p. 1002, and Irrigation in the United States, p. 693.

should be made from time to time to determine the trend of changes that may occur in the root zone in consequence of inadequate subsoil drainage or the accumulation of soluble salts. Such examinations of the soil of irrigated lands require special methods not only for the field work but also for reporting the findings. While definite progress has been made by soil scientists in the development of such methods, much may still be done to place this work on a sounder and more acceptable basis. The problem, however, is not so much to develop methods as to make practical application of methods already developed. Meanwhile the work of constructing and operating irrigation projects goes on. Avoidable mistakes are made and there are many failures. Questions are raised as to the permanence of irrigation agriculture because of uncertainties as to the causes of trouble. These are the reasons for emphasizing the need of careful, detailed soil surveys and land classification prior to the development of projects and the development and use of acceptable methods for ascertaining and reporting the conditions in irrigated soils.

The characteristics of a soil that have a special bearing on its suitability for agricultural use under irrigation are its water-holding capacity (the water capacity of the root zone), its permeability and natural drainage, and the nature and concentration of the constituents of the soil solution.

Water Capacity of the Root Zone

In considering the reservoir capacity of the root zone of the soil it should be kept in mind that there are three forms of soil water.[5] These may be described briefly as follows:

(1) Hygroscopic water, or water that is held by the soil when in equilibrium with the water vapor in the air, that is, in an air-dry soil.

(2) Capillary water, or water that is held as liquid films or masses around the soil particles in such a way as to exert no hydrostatic pressure; in other words in equilibrium with the force of gravity, but not in equilibrium with the moisture in the air.

(3) Hydrostatic water, or water that moves downward in the soil by gravity unless such movement is hindered by some barrier. This often is called free or gravitational water.

From the standpoint of reservoir capacity in relation to crop use it is only the water of the second form, capillary water, that is to be taken into account. Hygroscopic water is not available to crop plants, and hydrostatic water is available only briefly until it passes on, or as it is drawn into the capillary fringe from a lower saturated zone. The effective reservoir capacity of the root zone is therefore limited on the one hand to the quantity of water that may be held there against the force of gravity and on the other hand by the quantity held so firmly by the soil that it is unavailable to crop plants. This quantity in any case is determined by the texture of the soil, its content of organic matter, the nature of its colloidal complexes, and the depth of the root zone. In general, it ranges from 1 to 2 inches of water for each foot of root-zone soil. The depth of the root zone is also variable. In many irrigated soils it is limited by a saturated zone or water table; in some by bedrock, hardpan, or claypan; in others by the depth to which irrigation water penetrates; and in still

[5] See Water Relations of Soils, p. 897.

others that have no such physical limitations by the depth to which roots normally penetrate.

In view of the importance of reservoir capacity as a factor determining the suitability of soils for irrigation, it is manifestly desirable that an acceptable method be devised for determining quantitatively this characteristic of the soil profile. It should be possible to ascertain either by field or laboratory tests the reservoir capacity of representative layers of the soil profile, expressed as inches of water per unit of depth. This information together with the ascertainable facts as to any physical limitations of the depth of the root zone would serve as a most useful aid in classifying and mapping soils. The experienced soil scientist is able to judge the relative water-holding capacity of various soil types with a fair degree of accuracy and uses it as one of the criteria in classifying soils, but actual tests would be very valuable in helping him to form or check his judgments. Such tests would be useful also as a guide for selecting the program of irrigation best adapted to any situation or crop. Much of the misunderstanding and friction currently existing between water users and operation managers might be eliminated were such information available.

Permeability of the Soil

The permeability of a soil to water is as important as its reservoir capacity. The essential requirements are that the surface soil shall permit the inflow of water to replenish the root-zone reservoir and that the subsoil and substratum shall permit the escape downward of excess water or excess dissolved salts that might be injurious to crop plants if retained in the root zone. The permeability of soil to the movement of water is measurably influenced by its texture or particle size. That is to say that, other things being the same, a soil composed of large particles like sand is more permeable than one composed of small particles like clay. But this is not the whole story. Soil particles of whatever size may be cemented together to form impermeable layers commonly called hardpan; or the very finely divided or colloidal material in the soil on absorbing water may expand to form an impervious gelatinous mass.

These, rather than texture alone, are the real hazards to soil permeability. Both the cemented layers and the potentially gelatinous condition occur as the result of chemical reactions and are only partly dependent on soil texture. Cemented layers are formed by the deposition of soluble substances carried by percolating ground water. These may have been dissolved from the soil above or may have been carried in from outside sources. Silica, iron, and lime are the chief inorganic substances involved in the formation of cemented strata, but the decomposition products of organic soil constituents also contribute to the formation of impermeable strata, particularly in acid soils. The processes of decomposition, solution, transport, and deposition are the normal and continuing features of the evolution and differentiation of the soil profile. They operate slowly and the results become obvious in older soils, such as the hardpan soils of the Las Vegas and Pinal series. The younger alluvial soils, such as those of the Gila, Hanford, and Yolo series, do not show such differentiation.

The potentially gelatinous condition of the very fine soil material or colloids, sometimes called dispersion, deflocculation, or puddling, is another result of chemical reactions. These are known as reactions of base exchange.[6] They are well known and extensively utilized in industry, particularly in water softening. These reactions take place between the dissolved salts in a solution and certain of the finely divided or colloidal portions of the soil. In irrigated soils the exchange reactions of chief concern as affecting permeability are those of calcium and sodium. Sodium, in the soil colloid, tends to break down the soil particles and impair the permeability of the soil, while calcium tends to granulate the soil and make it permeable.

The trend of the reactions of base exchange is in the direction of an equilibrium between the soil and the dissolved salts in the soil solution in respect to the proportions of the basic constituents in each. Thus, if a change occurs in the ratio of calcium to sodium in the soil solution a change in the same direction occurs in the ratio of these bases in the exchange complex of the soil. It is not to be inferred that a condition of equilibrium implies that the ratios of the two constituents are the same in the soil and in the soil solution. That is to say, if the concentrations of calcium and of sodium were equal in the soil solution, the quantity of exchangeable calcium in the soil would probably be greater than the quantity of exchangeable sodium. This is because calcium has what is described as a greater "energy of replacement" than sodium.

The fact that changes in the permeability of the soil are caused by reactions of base exchange between the soil and its solution has come to be generally accepted only within recent years. This phenomenon of base exchange is currently the subject of much intensive investigation. Its occurrence and its implications are not limited to irrigated soils, nor are such reactions limited to the two elements calcium and sodium. But the exchange reactions of these two elements do affect profoundly the physical condition and the permeability of irrigated soils. The sustained productivity of irrigated land depends upon the maintenance of soil permeability, hence the importance of the subject and of further research work to unravel its complexities.

It is generally accepted as a fact that the dissolved salts carried to the soil in irrigation water become more concentrated in the soil solution as water is evaporated from the soil or absorbed and transpired by crop plants. Also, that the basic constituents of these dissolved salts participate in the reaction of base exchange in the soil and thus affect its physical condition and its permeability. Because the effect of the sodium constituent is to impair soil permeability, its concentration in the soil solution, relative to the concentration of calcium, is a matter of concern. The current investigational need is for convenient and acceptable methods for determining the composition of the dissolved salts in the soil solution and of the replaceable bases in the soil as related to permeability. Such methods would make it possible not only to ascertain existing conditions but also by successive investigations to ascertain the trend and the rate of change of conditions.

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[6] See General Chemistry of the Soil, p. 911.

THE SOIL SOLUTION

Water that is held by the soil in the root zone available for the use of crop plants is called the soil solution. The nature and concentration of the dissolved substances are matters of the first importance. This is because these dissolved substances are the only source of the mineral elements essential to plant growth, and also because they may include elements injurious to crop plants or the concentration of which in the solution may be such as to hinder the absorption of the water by the plants. Under conditions of copious rainfall and of free root-zone percolation the need may be to maintain in the soil solution adequate concentrations of the constituents that are essential to normal crop growth. With irrigation, however, and particularly with restricted root-zone percolation, there is another danger, namely, that excessive concentrations of dissolved constituents may accumulate in the soil solution. It is possible, of course, that the soil solution may be at the same time deficiently supplied with some essential constituent and contain an excess of others.

In irrigation farming it is important to maintain in the root zone of the soil an adequate quantity of water to supply the continuing needs of the crop plants, on the one hand preventing excessive root-zone leaching and on the other insuring sufficient leaching to prevent the accumulation of excessive concentrations of dissolved salts. In situations where the irrigation water is relatively pure, losses or injuries from excessive leaching may be avoided by restricting the quantities of water applied. But when the irrigation water contains relatively large quantities of dissolved salts it becomes necessary to use it in sufficient quantities to insure root-zone leaching and thus to prevent the accumulation of excessive concentrations in the soil solution. It follows, of course, that there must be effective subsoil drainage, either natural or artificial, to permit the removal of the percolating soil solution with its dissolved salts.

The occurrence of dissolved or of soluble salts in the root zone of irrigated land may be a natural condition existing before the use of irrigation water. In the survey and classification of land to be irrigated this condition of natural salinity is one of the factors to be appraised. Its correct appraisal is one of the important problems of the soil survey of an irrigable area. The investigational work of such a survey should have four objectives: (1) To determine the quantity or concentration of soluble salts in representative areas and their characteristic distribution in the successive layers of the root zone; (2) to ascertain their composition by analyses; (3) to identify, if possible, their source; and (4) to explore the possibilities of their removal by leaching and drainage.

Although it is now possible to determine approximately the total salt content of a soil and its degree of alkalinity by simple tests made in the field, there is need for improvement in methods to promote uniformity and precision. There is great variety among the methods currently in use. This statement applies particularly to the methods for determining the quantity or concentration of the soluble salts, and to the methods for obtaining samples of the soil solution for detailed analysis. For example, some investigators endeavor to determine by one expedient or another the total quantity of soluble material or the

total quantity of one or more of the soluble constituents contained in a unit quantity of soil. Others attempt to ascertain the concentration or the composition of the solution that may be extracted or displaced from a moist soil. The lack of widely acceptable methods for such work and the use of widely different methods by different investigators has made it almost impossible to compare their findings or to draw conclusions as to the essential facts. Because of this confusion there is no agreement on such questions as, What are the concentrations of any salt constituent that will impair crop growth, and, What is the trend or rate of change of salinity conditions in any given area?

The conditions of salinity in the soil solution are seldom static. Each periodic addition of water to it makes it more dilute and the continuing loss of water from it, whether by evaporation or by plant absorption, makes it more concentrated. Furthermore, it is subject to changes in the proportions of its constituents due to reactions with the soil, differential absorption by plants, and the dissolution or decomposition of the components of the soil. Finally, the solution itself is subject to movement within the soil either laterally or vertically in response to hydrostatic forces. These changes and movements add to the difficulty of ascertaining and reporting the facts as to what are the actual conditions of salinity in the field that cause observable plant responses, or as to what are the actual changes in conditions that occur from time to time as the result of irrigation.

Notwithstanding these ever-changing conditions of salinity within the root zone it is possible to ascertain and to report certain quantitative facts that are significant. These facts include: (1) The depth of the root zone; (2) the quantity of water in depth per unit area (e. g., inches of water per acre) held in the root zone (a) when at field capacity and (b) when at wilting point (wilting coefficient); and (3) the quantity of dissolved or soluble salts in the root zone expressed as tons per acre. With these facts available it is possible to estimate the concentration of dissolved salts in the soil solution and the range of concentration to which the crop plants are subjected between irrigations. It is believed that this method of appraising the conditions of salinity is better than the alternative method of reporting the soluble salts in terms of percentage of the dry weight of the soil. There are two reasons for this choice of methods. One is that all of the precise data as to the reactions of crop plants to salt constituents are reported in terms of solution concentration, and the other is that in the absence of information as to the water relations of the soil it is not possible to estimate the concentration of the soil solution from the data of salt percentages with reference to the dry weight of the soil.

Constituents of the Soil Solution

It is essential to an understanding of plant and soil reactions to the composition of the soil solution to keep in mind that it is the salt constituents rather than the salts that cause the reactions. A salt such as sodium chloride, when it passes into solution, dissociates or separates into its two components, sodium as a basic or positively charged ion and chloride as an acid or negatively charged ion. This is true for all of the electrolytic salts that are characteristic of soil solutions. It is these constituent ions that are measured in making the analyses of

solutions, and it is also these ions, acting independently, that are absorbed by plants or that participate in reactions between the soil solution and the soil.

In view of these facts it is manifestly of doubtful utility to describe the composition of a soil solution by naming a list of the combinations that might be formed from the identified constituents. Similarly it is of questionable value to characterize a solution or a salt complex as having certain proportions of black alkali and of white alkali. At best these designations imply theoretical concepts that have little significance. The characteristics of a soil solution may be most concisely and accurately described by giving its total concentration, *together with either the actual or proportional concentrations of its more important constituents.*

The soil-solution constituents ordinarily identified by analysis in irrigated areas are the following: (1) Calcium (Ca), (2) magnesium (Mg), (3) sodium (Na), (4) potassium (K), (5) carbonate and bicarbonate (CO_3 and HCO_3), (6) sulphate (SO_4), (7) chloride (Cl), and (8) nitrate (NO_3). In some situations the elements boron and selenium occur as parts of ions in the soil solution and are also identified. Certain physical characteristics of the solution are also determined, e. g., the specific electrical conductance, and the hydrogen-ion concentration. Of the eight constituents enumerated above, the first four are cations or basic ions while Nos. 5 to 8 are anions or acid ions. Some of these constituents are known to be essential to plant growth. Other elements, such as iron, manganese, and phosphorus, are also essential but rarely if ever do they occur in harmful concentrations in irrigated lands.

While crop growth on irrigated land may be restricted because of the deficiency of certain solution constituents such as nitrate, phosphate, potassium, or iron, the more striking and disastrous losses are caused by excessive concentrations of such constituents as sodium, chloride, and sulphate, with occasional injury from boron or selenium. The carbonate-bicarbonate constituent is not here included in either category because it is seldom if ever deficient and there is little if any valid evidence that it is ever directly injurious. The situation as to calcium and magnesium calls for special comment. These constituents are almost universally present in irrigation waters and in the soil solutions of irrigated land, and their concentrations are seldom below the maximum plant requirements. On the other hand, calcium is seldom if ever found in the soil solution in concentrations high enough to be injurious to crop plants. This is because it is usually associated in the solution with sulphate and bicarbonate, with which it forms salts of such low solubility that it is precipitated from solution before it reaches injurious concentrations. It is theoretically possible to have injurious concentrations of magnesium in the soil solution, but actually this does not occur frequently.

Because both calcium and magnesium participate in reactions of base exchange between the soil solution and the soil, the occurrence of these constituents in the soil solution is more likely to be beneficial than harmful. Exchange reactions by which calcium and magnesium pass from the solution into combination with the soil tend to improve the physical properties of the soil in respect to tilth and permeability.

Consequently the application of irrigation water relatively rich in calcium and magnesium is likely to benefit the soil and is not likely to injure the crop plants.

In the light of our present knowledge and the considerations discussed above it is manifestly not possible to make two lists of soil-solution constituents, one list to include those that are beneficial and the other those that are harmful. It seems highly probable that all of the constituents named above and probably many others are beneficial if not essential to plant growth. The adverse effects of deficiencies of some of them are well-known. With respect to each of them there is probably some optimum concentration below which growth is impaired and above which there is some injury. There is very little precise information or agreement among investigators as to these optimum concentrations for the several constituents. There are differences of opinion among plant physiologists even as to whether some of these constituents are beneficial at all. There are also wide differences of opinion as to what concentration of any given constituent either above or below the optimum may cause appreciable depression of growth with any given species of plant under any given set of conditions. In view of these facts it is manifestly not possible at the present time to state the limits of tolerance of crop plants to excessive concentrations of the dissolved constituents of the soil solution.

THE QUALITY OF IRRIGATION WATER

Any adequate consideration of the soil conditions of irrigated lands must include the quality of the irrigation water. This is because irrigation water, unlike rain water, contains dissolved substances, often in substantial quantities, and these substances accumulate in the irrigated soil and may, in time, cause profound changes in its character. It is not unusual to apply in a single season as much as 2 or 3 feet in depth of irrigation water. Nor is it unusual that an acre-foot of irrigation water may contain as much as a ton of dissolved solids. Thus, the addition annually of 2 to 3 tons of dissolved solids to an acre of irrigated land is not uncommon. By way of comparison it may be remarked that when soluble salts are used as commercial fertilizers the ordinary rate of application is 200 to 300 pounds per acre.

Some of the dissolved constituents in irrigation water, such as potassium and nitrate, may be directly beneficial to crop plants. Others, such as calcium and magnesium, may under some conditions have a beneficial effect on the physical condition of the soil. There remain, however, other constituents—chloride, sulphate, and sodium, for example—that are seldom beneficial to the soil or to the crop plants and in the higher concentrations are definitely injurious The effects of these dissolved constituents, whether good or ill, are seldom immediately apparent. If the concentrations are low, irrigation water may be used for many years before the evidences of injury become obvious. Unfortunately it is a fact that by the time the effects of injury, particularly to the soil, become apparent, thay have progressed so far that remedial measures are likely to be expensive and to require a long time to become effective.

The effects on the soil of the dissolved constituents of irrigation

water may operate in two ways: (1) On the physical properties of the soil mass; (2) on the concentrations of soil solution. These two kinds of effects may occur separately or together. In considering either or both it should be kept in mind that when irrigation water is applied to the land, most of the water is dissipated into the air either by direct evaporation from the soil or by transpiration from plants, while the dissolved constituents are not so dissipated. Some of them may be absorbed by plants to a limited extent, but for the most part they remain in the soil unless removed from it by drainage. Thus it follows as a matter of course that the soil solution is always more concentrated than the irrigation water, except in instances where rainfall or natural flooding have a marked effect in leaching the soil. How much more concentrated the soil solution is will be determined by the quantity and effectiveness of the drainage.

The physical changes that occur in an irrigated soil are chiefly the results of reactions of base exchange. These reactions are induced by changes in the relative concentrations in the soil solution of the basic or cation constituents such as calcium, magnesium, and sodium. Thus if, in the irrigation water and in the resulting soil solution, the proportion of calcium and magnesium to sodium is substantially the same as that of the original soil solution, there should be no change in the physical properties of the soil. But if these proportions are different in the irrigation water, there would follow a corresponding change in the soil. The change to be feared is the one in the direction of a higher proportion of sodium, because the increase of this exchange constituent may lead eventually to dispersion of the soil particles, a tough or rubbery condition of the soil mass, and to impaired conditions of soil tilth and permeability.

In good agricultural land in normal condition the exchangeable constituents are mostly calcium and magnesium. There are, of course, acid soils in humid regions in which exchangeable hydrogen occurs, but in neutral or alkaline soils of good tilth and permeability calcium and magnesium are the dominant exchangeable constituents. The use of irrigation water in which sodium is the chief basic constituent is almost certain to have an adverse effect on such a soil. The effect may be slow to appear unless the concentration is high both relatively and absolutely, but it is inevitable unless some corrective measures such as the artificial application of calcium are used.

The gradual accumulation of dissolved constituents in the soil solution of irrigated land may occur along with or independently of changes in the physical condition of the soil. The two phenomena are seldom wholly unrelated. To some extent the occurrence of high concentrations of such constituents as sulphate and chloride tend to offset or counteract the dispersing effects of sodium. But the chief concern over high solution concentrations in the soil has to do with their direct effect on plants. These dissolved constituents in the soil solution appear to be injurious in two ways. They tend to inhibit the absorption of water by the plant roots, and some if not all of them when present in excessive concentrations are absorbed by the plants and cause internal derangements of growth processes. Much remains unknown as to just how these toxic effects occur. There is much uncertainty also as to the limits of plant tolerance to each of the salt

constituents. There is no question, however, as to the fact that the dissolved salt constituents of irrigation water do accumulate in the soil and do impair its productivity.

Fortunately these injurious consequences may be prevented in many instances. The accumulation of these soluble salt constituents results from inadequate irrigation or inadequate drainage. If drainage, either natural or artificial, is adequate, the accumulation of salts in the soil may be prevented by the use of enough irrigation water to leach the root zone at least occasionally and thus carry the salts away. In the survey and appraisal of irrigable land it becomes essential, therefore, to give consideration to the conditions of permeability of the soil and subsoil. Unless these conditions are naturally favorable to drainage and to the removal of the soluble residues of irrigation, the danger of impaired productivity from salt accumulation is serious.

IMPORTANCE TO IRRIGATION AGRICULTURE OF CONTINUED RESEARCH

The history of irrigation shows that there have been many successes and many failures. The determining factors are not always easy to identify, but the majority of them may be traced to unfavorable conditions of water supply, soil, and drainage.

Irrigation agriculture is beset with most of the hazards that plague ordinary farming, such as weeds, insect pests and plant diseases, and the uncertainty of continued soil fertility. It is not even wholly free from the fear of drought. Its operation costs are relatively high because of water-service charges and the labor of irrigation. To meet these higher costs the crop yields must be relatively large, and there should be a reasonable prospect of long-continued productivity. Such a prospect appears to depend upon the wider utilization of the fruits of experience now available, together with the extension of knowledge concerning some of the fundamental conditions of the soil, its reactions to the constituents of irrigation water, and the effects of these constituents on crop plants.

The more important causes of declining crop yields peculiar to irrigated land lie in the conditions of the soil solution and could be prevented if they were better understood. The conditions of the soil solution are, in turn, largely due to the characteristics of the irrigation water. Thus the general problem of the permanence of irrigation agriculture insofar as it depends upon the sustained productivity of irrigated land is directly related to the quality of the irrigation water. The dissolved constituents of the irrigation water may react with the soil to cause changes in its character or they may accumulate in the soil solution and thus directly injure the crop plants. Where the potentialities of injury of either kind exist and are known in advance, remedial measures may be taken, often at small expense. It is much easier to prevent injury than to deal with it after it has developed.

In view of the fact that the extent of the irrigable land in this country greatly exceeds the area for which there is available irrigation water, the first objective should be to select the best land for irrigation development. To do this wisely there is need for wider appreciation and clear understanding of those factors of soil, of topography, and of

drainage conditions that are important in determining the continuity of successful irrigation. Even with the best available land there is further need for information as to the trend of changes that follow irrigation to serve as a guide to proper irrigation and drainage management. The program of management must be adapted to local conditions.

The continued development and extension of irrigation is one of the important causes of changing conditions in respect to the quality of the irrigation water. Along any given stream the diversion and use of water not only diminishes the quantity available below it but affects the quality also. The drainage water returned to the stream from irrigated land carries most of the dissolved salts in the water originally diverted, but the volume of returned water is much less. Thus as the complete utilization of water resources is approached, the problem of dealing with the dissolved salts becomes increasingly acute. This is one of the more fundamental problems of maintaining a permanent irrigation agriculture. To deal with it efficiently and successfully calls for continuing investigation in the field of soil science and the practical application of the findings of such investigation.

EQUALLY *as important as the problem of getting water to irrigated land is the problem of getting it away again without leaving an accumulation of harmful salts in the root zone. This article considers the various methods that may be used—tile drains, deep knifing, open ditches, drainage wells—in relation to the character of the soil and the topography.*

Drainage in Arid Regions

By James Thorp and C. S. Scofield [1]

SOILS in many parts of arid and semiarid regions are poorly drained in spite of low rainfall. Flat areas or depressions with no natural drainage channels and low-lying river flood plains and lake flats are commonly wet during all or a part of the year, even in virgin desert regions. Other areas in low-lying positions or having tough or impermeable subsoils and substrata may give little or no outward evidence of poor drainage under natural conditions, but when such land or adjacent land is put under irrigation the level of the ground water rises and waterlogging results. This condition may even occur in places on uplands.

Poor drainage in the arid regions commonly leads to the accumulation of soluble salts on or near the surface [2] and these salts inhibit or prevent the growth of most crop plants. Drainage is the first step necessary in the reclamation of saline and alkali soils.

IRRIGATION AND DRAINAGE GO HAND IN HAND

Land in arid regions must be irrigated if it is to be used for crop production, and in some places this produces waterlogging. Within many of the irrigated districts are areas where the conditions of soil and topography are such that ground water forms a saturated zone in the subsoil, invading the root zone from below and impairing the productivity of the soil. The extent of soil injury by waterlogging is influenced to some extent by the character and concentration of the dissolved constituents in the subsoil water. But even where these dissolved salts do not differ greatly in character or concentration from those of the irrigation water, crop injury may result simply from

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[2] See Soil, Water Supply, and Soil Solution in Irrigation Agriculture, p. 704.

restriction of the root zone. In general, however, the subsoil water is much more concentrated than the irrigation water, and crop injury is due partly to its salinity. The condition is aggravated by the concentration of salts at the surface due to the evaporation of rising capillary water.

In any event it is essential that root-zone restriction by subsoil water be prevented. Movement of water downward and out must be maintained. This is the purpose of drainage. In many instances it will be essential to install drains to keep the level of ground water below the point where it may be drawn to the surface by capillarity. This depth ranges from 2 to 10 feet, depending on the texture and structure of the soil.

In order to insure sustained productivity of irrigated land the quantity of irrigation water applied must be sufficient not only to supply the crop requirements but also to leach the root zone, at least occasionally, to remove the dissolved salts. Thus the purpose of drainage should be not only to remove surplus subsoil water but also to remove the salts that are continuously brought to the land in the irrigation water. The quantity of dissolved salts removed from the area by drainage should equal or exceed the quantity brought in.

Past Mistakes

Some reclamation engineers have assumed that gravelly or sandy substrata will provide sufficient natural drainage facilities to render the establishment of tile drains and ditches unnecessary. This is probably true in many cases, but not in all, as experience has proved. For example, the gravelly terraces of the Shoshone River in Big Horn Basin, Wyo., (*96, 406*)[3] seemed to furnish ideal conditions for irrigating desert soils without the expense of constructing drainage ditches. A large, nearly flat area near Powell, Wyo., was accordingly irrigated. Crops grew splendidly for a year or two and then, as the water table came nearer and nearer the surface, salts began to accumulate, first in depressions and on thin soils, and then over almost the entire area. Most of the farmers faced ruin, and drainage was the only solution. Accordingly a network of deep drainage ditches was established and to these were connected still finer networks of tile drains that reached all parts of the area. It was then possible to establish a downward movement of water to wash out the salts and restore the prosperity of the Powell district.

In spite of the gravelly substrata of the Shoshone River terraces, excess water could not quickly drain away. This was because the materials had been laid by the river on an unevenly eroded rock surface and the water collected behind rock reefs, the existence of which would not be suspected by studying surface conditions. Figure 1 illustrates the principle involved. Soils were medium-textured and easily pervious, substrata were gravelly and porous, but the rock bench beneath was too uneven to permit the water to escape freely. In other places the position of the land is so low in relation to creeks, rivers or lakes that there is no internal drainage outlet and a high water level exists regardless of a pervious condition of the soil and substratum.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Some engineers have been prone, in the past, to plan irrigation projects largely on the basis of whether or not it was economically feasible to bring water to the soil. Little attention was paid to the quality of the soil in many of the reclamation projects, which as a result were as likely as not to be failures. To cite an example—again from the Big Horn Basin in Wyoming—water was led to a large area of gently sloping land near the present village of Frannie. No plans were made for draining the land and it became thickly coated with

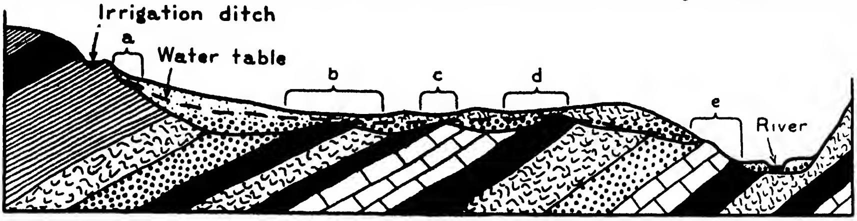

FIGURE 1.—How an uneven rock floor on a gravelly terrace prevents excess irrigation water from draining away. The bracketed areas—*a*, *b*, *c*, *d*, and *e*—soon become impregnated with salts when the land is irrigated. (The hatched areas represent different rock formations.)

salt crusts within a few years. Investigation of the soils proved that the greater part of them were heavy plastic clays and clay loams of the adobe type and that most of them lay on soft, salty clay shales at a depth of less than 3 feet. It is practically impossible to establish downward movement of water through such materials. When wet, they swell and become jellylike, so that little or no water can pass. Tiles become filled with mud and open ditches tend to cave in. Most of this project had to be abandoned because it could not be drained.

Examples similar to those given above could be cited for practically all of the semiarid and arid States.

DRAINING IRRIGATED LANDS

When irrigation projects are under consideration, first thought should be given to the quality of the soil and the natural drainage or the possibilities for establishing adequate drainage. Tile drains have a real but limited usefulness in such areas. They may be used where substrata are gravelly or coarsely sandy, but are likely to become clogged very easily if they are placed in soils containing high percentages of very fine sand, silt, and clay. In places sandy alluvial materials are interstratified with thin layers of clay, as in the case of the Gila soils of southwestern Arizona and of the Imperial soils of the Imperial Valley, Calif. (*389*, *476*). These tend to hold water at various levels and so encourage salt accumulation. Close spacing of open ditches is essential with such soils unless the land is deeply subsoiled, in which case wider spacing will probably serve. Deep knifing (a process analogous to deep subsoiling) breaks up the clay strata and enables water to penetrate to lower levels. The method has been successfully used on claypan soils in semiarid southern Puerto Rico where soils are deeply knifed every few years.

If the soils are highly alkaline (containing sodium carbonate or sodium clay in appreciable quantities) they are deflocculated when

wet and will flow through the crevices and fill the tile drains. In such cases open ditches will be more effective in removing excess water.

Saline or alkali soils of heavy texture and low calcium content may drain satisfactorily until most of the soluble material has been removed. They then run together to form a sticky, jellylike mass through which water passes with difficulty and on which satisfactory crops cannot be grown. Irrigation and drainage both will fail on these soils unless they are treated with heavy applications of gypsum or sulphur. After such treatment it will be possible to establish downward movement of irrigation water through the soil and into the drainage ditches. The cost of this type of treatment is likely to be prohibitive except for the reclamation of lands having a potential value of several hundred dollars an acre.

Ground water in an irrigated area does not all come from the percolation of water applied to the fields. In many irrigated areas the irrigation water is distributed through unlined canals. The percolation losses from these is often large, sometimes amounting to 30 or 40 percent of the water diverted from the stream. In such instances lining canals with concrete is useful both to save valuable irrigation water and to reduce waterlogging of lower lying lands. Some irrigated lands are situated along stream channels and are so low that unless protected by levees they are subject to overflow during flood periods. Under such conditions the ground water may be replenished from the stream channel

Location of Drains

Intercepting drains are often effective when placed just below and parallel to irrigation ditches, or parallel to the levees bordering streams. They may also be effective at points where there are abrupt changes of slope from steep to gentle and flat as at the base of a bluff or escarpment. On river terraces and flood plains, the higher levels are likely to be near the stream or along former stream courses. The land tends to slope away from the stream bank or natural levee toward the inner part of the plain or terrace where there are usually lower strips of land. In such places water accumulates first when the land is irrigated. Very often these are the best locations for the large drainage canals, and feeders can be brought to them from higher lands on each side.

Near the seacoast, or in very flat areas, it is sometimes feasible to establish a drainage network from which the water can be pumped through a dike into the sea, river, or lake. Water is pumped over a dike into the Colorado River in Yuma Valley, Ariz. In some situations it is possible to establish tidal gates which automatically let the water out to sea when the tide is low, but prevent salt water from coming in at high tide.

Drainage Wells

Wells are used in at least two ways to drain areas affected by salts. In southern Idaho, for example, drainage water finds its way into tubes and fissures in underlying lava (basalt) beds. It follows these natural drainage channels to places where they approach the surface on lower slopes. Seepage results and salt accumulates. It has been

found practicable to drain some of these areas by intercepting the underground water courses with deep wells from which the water flows under hydrostatic pressure (fig. 2).

In Salt River Valley, Ariz., it has been found practicable to keep the water table low by pumping water from deep wells and mixing it with

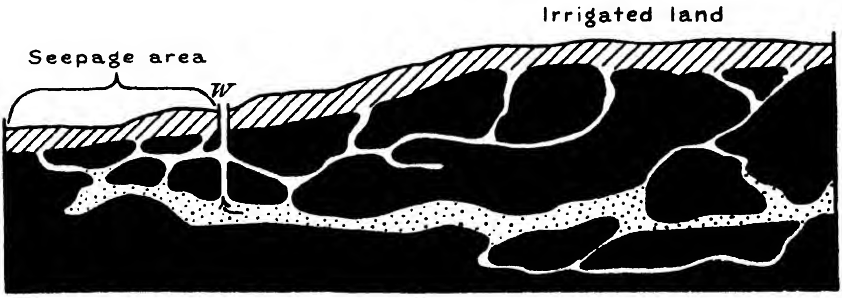

FIGURE 2. Cross-section showing dark-colored lava deposits (basalt) underlying irrigated lands in southern Idaho. Water follows cracks and tubes in the rock to lower slopes where seepage develops. The drainage wells (*W*) pierce the rock to the porous stratum and intercept the seepage water, which flows upward to the surface under hydrostatic pressure.

the irrigation water (fig. 3). By this means the water table can be kept a safe distance below the surface. The chief danger lies in the possibility of making the irrigation water too saline. This should be carefully checked and the mixture of river water and well water never allowed to become too salty for use on crops.

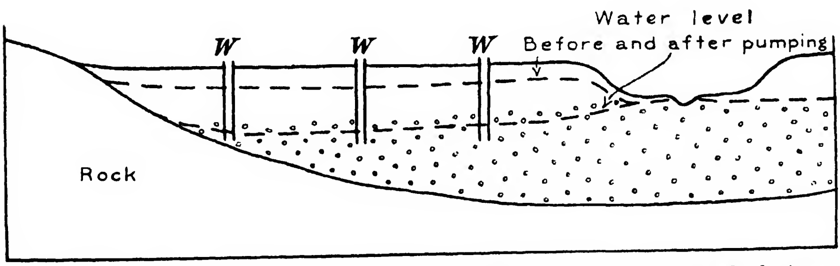

FIGURE 3.—By pumping water from the gravelly substratum through drainage wells (*W*) and mixing with irrigation water in Salt River Valley, Ariz., the water table is kept well below the surface.

REQUIREMENTS OF AN EFFICIENT DRAINAGE SYSTEM

In order to insure that a drainage system is functioning effectively in an irrigated area the operation records should show: (1) That the ground water is being kept below the root zone of the soil; (2) that the quantity of dissolved salts annually removed from the area by drainage equals or exceeds the quantity brought in by the irrigation water; and (3) that the quantity of irrigation water actually applied to the land is large enough to leach the salt residues from the root

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zone. To obtain information on (1) involves the use of observation wells; (2) calls for the measurement and analysis of the irrigation and drainage waters; and (3) necessitates a program of sampling and analyzing the soil solution to observe the trend of conditons as to its content of soluble salts. In general the concentration of salts in the soil solution of the root zone should not be much higher than that of the ground water if root zone leaching is effective.

The problem of obtaining effective drainage is not solved merely by removing excess ground water. Nor is it solved by obtaining a favorable salt balance as between the irrigation input and the drainage output. The crux of the problem lies in the root zone of the soil, or specifically in the soil solution of the root zone. This is the source from which the crop plants must obtain their water. If they are to thrive year after year the soil solution must be dilute enough in respect to dissolved salt constituents so that the crop plants may continuously obtain the water they need without absorbing with it harmful quantities of dissolved salts.

WHAT TYPES of soil in the humid region require artificial drainage? Is it profitable to drain peat and muck? In general, is it better to use open drains or tile drains? What conditions call for the uniform system and what for the intercepting system of tile drainage? What factors determine the depth and spacing of tile drains? How should intercepting drains be located? Such questions as these are discussed in this article.

Drainage in the Humid Regions

By JOHN R. HASWELL[1]

THE DRAINAGE of imperfectly drained and saturated soils used in crop production is a well-established practice. The installation of artificial channels or underdrainage for the removal of surplus water from both the ground surface and the soil, to a fair root depth, is limited only by the farmer's appreciation of their need, his means to pay for them, and the ability of the different soils to respond to drainage improvement and give an adequate return on the cost.

For years some farmers have seen wet spots in good fields "drown out," with loss of labor, fertilizer, and seed, not to mention the seldom-considered rental value of the land. Yet they made little or no attempt at drainage until they changed from horses to tractors. When the heavier machinery mired down they decided to drain. Realizing the seriousness of the situation in holding up the sale of farm machinery, and possibly wishing to improve the farmers' ability to buy new equipment, one manufacturer published a bulletin on drainage (*153*),[2] even though the company produced no drainage tools.

NEED OF DRAINAGE

Besides the necessity for making wet spots firm enough for farming operations and squaring up fields for efficient working, drainage may be looked upon as a form of crop insurance.

Land saturated with stagnant water is late in the spring, killing frosts come early in the fall, and winter heaving is more severe than on well-drained soil. Heaving often plays havoc with alfalfa and

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

winter wheat. The benefits from drainage—at least 10 advantages are usually listed—are too well known to need enumeration here; the Department of Agriculture and many of the State colleges have publications that amply cover the subject (*192, 315, 344*). The benefits result primarily from the removal of surplus or gravitational water in the soil and its replacement by air when artificial drains are supplied. However, the drains should not be so deep that needed soil water cannot be drawn upward by capillary action from the subsoil when the growth of the crop depletes the moisture in the root zone. There is seldom any danger of this except in very sandy soils or in peat or muck.

Soil Types Requiring Drainage

Certain soil series, primarily products of poor drainage conditions, are noted for their drab or gray subsoils, usually mottled with yellow, red, or brown and containing iron concretions in places. The mottled subsoil is one of the best poor-drainage indicators. There are other soils in the same localities, developed under better natural drainage conditions, that are closely associated with the cold, wet types. Thus, there are well-drained Sassafras soils associated with Elkton soils that are intermittently wet and dry. The former are well oxidized and brownish while the latter are lighter and more grayish in color and lower in agricultural value.

When small spots of Elkton soils occur in fields composed mostly of members of the Sassafras series it would be well to attempt to make the cultivated area uniform by drainage. The addition of lime and organic matter assists in the process where flocculation and lightening are needed. Similar observations for the entire country are given in a Department of Agriculture bulletin, Soils of the United States (*241*).

The heavier members of the Volusia series require artificial drainage for their highest agricultural development. On these soils it is sometimes difficult to get corn to mature or even to make a satisfactory growth for silage. Since much of the area they cover is in dairying sections of New York and Pennsylvania, supplemental drainage is necessary in order that at least a major portion of the roughage in the dairy ration may be produced on the farm.

Drainage experiments in progress by the agricultural experiment station at the Pennsylvania State College on Volusia test plots in Bradford County show the need of drainage and the benefits of tile drains. The corn crop on one of the undrained check plots is shown in figure 1, *A*. It was pale in color, had few ears, and produced about 9 tons of silage corn per acre. With all other conditions the same, the adjoining plot (fig. 1, *B*), which was tile drained, produced more than double the silage corn, with a big ear on practically every stalk. The corn on the drained land was much darker green.

The first root growth is in the topsoil. Some say that a limited growth of fine "water" roots may penetrate below the water table, but these roots have little value in feeding the plant and are replaced by thicker, more healthy ones if the soil dries off in time. Poor drainage results in a set-back to the crop, and if the season should turn droughty the shallow roots already established do not draw on a sufficient depth of soil to produce a satisfactory crop. On soils of

good physical character a well-drained condition promotes good crops in both wet and dry years.

The classification of soils in the various series according to surface texture, from sand and gravel to clay, is well known. The first two are inclined to be droughty, and many clays are slow to drain; but

FIGURE 1.—Corn makes better growth on drained land: *A*, Corn on undrained Volusia test plot—light in color, low in yield, with few ears; *B*, corn on tile-drained Volusia plot adjoining—dark green in color and yielding more than double the ensilage where drainage was poor. Tile laid 30 inches deep, and spaced 34 feet.

under proper drainage conditions many of the heavy soils crack on drying and flocculate to an easily worked crumb or granular structure. Much depends on proper plowing, cultivation, liming, and applications of manure and fertilizer. Between the extremes are various loams such as sandy loam, loam, silt loam, clay loam, etc. Strongly

acid silt loam and silty clay loams are inclined to be tight, difficult to drain, and often lifeless, like putty. Close spacing of shallow drains may dry them out sufficiently for a fair growth of crops, but in many instances the cost of the drains is several times more than the land is worth. Often the crops on such land do not make an adequate return on the investment. On the other hand, soils of similar texture but containing more lime and organic matter can be drained rather easily and may become very productive.

One of the indications of previous wetness in an old field is the presence of "lands"—sometimes called ridges and furrows—made when plowing by farmers who did not appreciate the necessity of removing the ground water and were satisfied if the surface seemed dry on the ridges. Tile may be put under the dead furrows as a cheap substitute for close, uniform drainage. The water gathers over the tile and ultimately drains away.

The presence of sand in heavy clay soils is welcomed in some sections by drainage engineers as an indication of a soil easy to drain. In other localities the reverse is true, as the sand tends to form a hardpan mixture that interferes with the operation of tile drains. The so-called clay in such instances includes much silt, and when there is a lack of organic matter the soil is inclined to be sticky, not given to the formation of a crumb structure on drying, and slow in developing pores down to the tile level. In extreme conditions the pores may never form sufficiently for the drains to work satisfactorily.

There are a number of local names which immediately bring to mind the picture of land too wet to farm. Among these are crawfish, flatwoods, post oak, hog-wallow prairie, hardpan, and buckshot.

Draining Peat and Muck

The drainage of peat and muck soils presents difficult problems. These deposits shrink and subside after drainage, and when they are dried out excessively they are a serious fire hazard. In some cases shrinkage lowers the peat surface nearly to the outlet level and further drainage by gravity becomes impossible. This is true of much of the peat and muck of the Everglades in Florida. When the beds are deep, with no mineral substratum to serve as a base, the tendency of some drainage systems is to lower the ground water too much. This can be overcome by placing dams in ditches and stop gates in tile drains, though they prove quite a nuisance. The use of muck for truck crops, peppermint, and cranberries will always be practiced in spite of the ever-present danger of setting fire to the land. On cranberry bogs the sand covering and flooding structures are safeguards. As a protection against bog fires, some peppermint farmers maintain fire trucks with pumps.

Sometimes small areas of peat or muck occur in large fields of mineral soil and are drained in an attempt to make the land uniform for farm operations. No additional phosphate or potash is supplied during seeding on these small muck areas, and serious lodging of small grains sometimes results. If the organic deposits are shallow, this can be partially overcome by mixing mineral soil with the organic materials by deep plowing.

Since muck and peat usually occur in low places, there is danger of

summer frosts, especially in the most northerly parts of the United States. Alway (*11*) notes that drainage may somewhat lessen the danger from frost but cannot be expected to overcome it. He suggests coating peat with sand, clay, or loam. He also warns against the drainage of large peat deposits as follows:

> Extensive ditching projects far in advance of reclamation, which have been common in northern Minnesota, are to be attributed to the prevailing erroneous belief that drainage alone will make the peat lands productive.
>
> When immediate reclamation is not purposed the grass-covered bogs had better be left to serve as wire-grass meadows, or drained just enough to allow the cutting of wild hay, while the bogs with merchantable timber should be kept under proper forest management and all others left undisturbed until the would-be developers have satisfied themselves by systematic investigations and small-scale trials that reclamation will prove profitable.
>
> It appears that at present in the case of the greater portion of our immense peat acreage, the profit of reclamation is to be regarded as extremely doubtful, even under the most skilled supervision and with every resource and facility for conducting the work economically, while many extensive tracts could be improved only at a loss.
>
> There is, however, much peat land that might at once be profitably reclaimed, especially where the owners already live upon it or where it forms parts of farms consisting largely of mineral soil.

A small area of drained peat soil in southern Georgia was taken out of cultivation because of the extreme discomfort to mules and men when it was worked. Local residents blamed the trouble on "alkali" or some other chemicals. S. W. McCallie, State geologist, first recognized the trouble as being due to spicules of sponges (*90a*). They are microscopic glasslike particles with very sharp points and are the residue of fresh-water sponges. As such sponges have had a wide distribution it is probable that the itch so often complained of by workers on muck and peat lands is due to their presence in the soil. The studies made of new areas before draining could easily include a microscopic examination for such particles.

A practice that helps to make the reclamation of peat lands successful is the use of very heavy rollers to compact deep deposits. This is mentioned by Alway (*11*) and also by Harmer and Musselman (*144*), who give drawings for constructing such a roller. Where heavy wheel tractors are used the same effect is produced.

TYPES OF DRAINAGE

Drains are of two types—open drains and underdrains. Open drains are merely an improvement of the natural surface drainage system of creeks and rivers. Except possibly for a few soils and crops they are not to be considered as field drains in well-ordered agriculture. Their chief purpose is to serve as outlets for field underdrains. In most cultivated fields the open ditch seldom has sufficient depth unless it is unduly wide, which makes it occupy valuable land. The banks on most soils get packed from turning implements and the trampling of stock, so that pools of water often remain near the ditch, and they also harbor weeds, insects, and other pests. Tile drains, on the other hand, can be put at an efficient depth, occupy no land surface, and permit the field to be cleanly cultivated; and after they are established, the water percolates more rapidly through the soil into them. Tile underdrains are permanent and seldom need cleaning when correctly installed and maintained with a clear

outlet, whereas an open ditch requires regular maintenance if it is to remain satisfactory.

A real use for open ditches is in draining some forest lands where "the aim of drainage for forestry purposes is to keep the water changing rather than to create a 'bone dry' condition" (*20*).

A farmer short of cash can often materially improve the drainage conditions on his land by constructing shallow ditches in the low parts of the fields with the idea that later when funds are available he can put in more efficient tile drains. Such shallow ditches are effective only for moving surface water quickly and making the field ready for cultivation sooner than would otherwise be possible, but the benefits usually more than pay for the labor and cost.

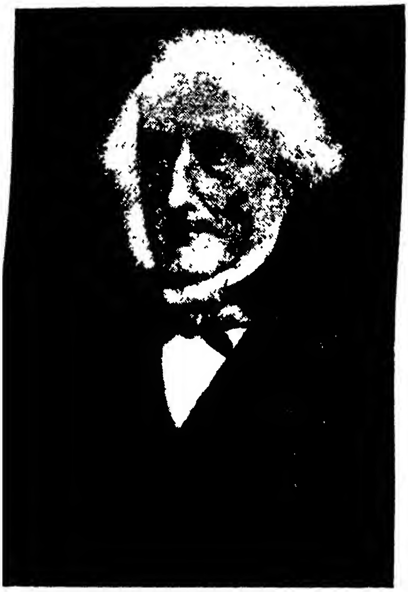

FIGURE 2.—John Johnston, the first man to lay drain tile in the United States.

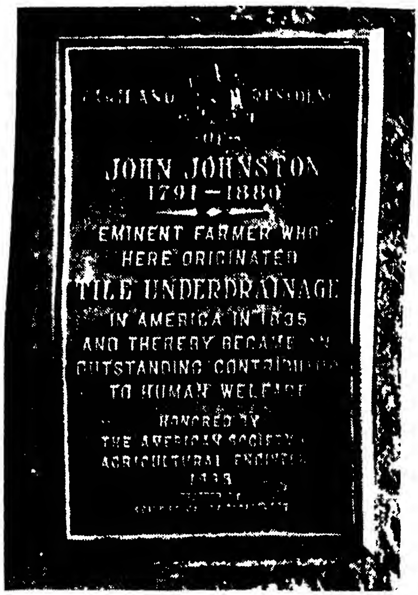

FIGURE 3.—Marker on the Johnston farm near Geneva, N. Y. Inscription composed by Liberty Hyde Bailey.

Construction of Open Drains

It is not the purpose to take up here the problems of large drainage districts. Their design and construction is of more interest to the engineer than to the farmer. The ditches are usually considered satisfactory if a sufficient depth is provided for field drains and freedom from flooding, except when desired.

Floating dipper dredges were formerly the principal machine used for construction, but they now have to compete, particularly in smaller work, with crawler-type dragline, wheel excavators, and dipper machines. The use of straight nitroglycerine dynamite for ditch blasting is spreading. When the soil is saturated and uniform sticks of fairly high percentage are used, the explosion will "propa-

gate" from one charge to the next. This method requires only one cap and is far more economical than having a detonator in each charge. Dynamiting is readily understood by farmers and affords an easy means of opening silted creeks and ditches, besides making new open ditches. The soft bottom resulting from the blast is unsuitable for laying tile drains. Under most conditions, explosives have not been helpful in loosening a tight subsoil (*369*).

TILE DRAINS AND MOLE DRAINS

Many volumes have been written on the subject of tile drains since John Johnston (figs 2 and 3) laid the first drain tile in the United States in 1835. He maintained that he never made any money farming until he had drained his land. The 70 miles of tile on his 300 acres are still in successful operation, having been carefully placed on a good grade and emptying into a free outlet.

Much money can easily be spent on drainage with very unsatisfactory results unless the systems are carefully laid out and constructed. Often an unschooled laborer with a knack of tapping water-bearing strata will do a better job than the engineer relying on handbooks and having no practical soil experience.

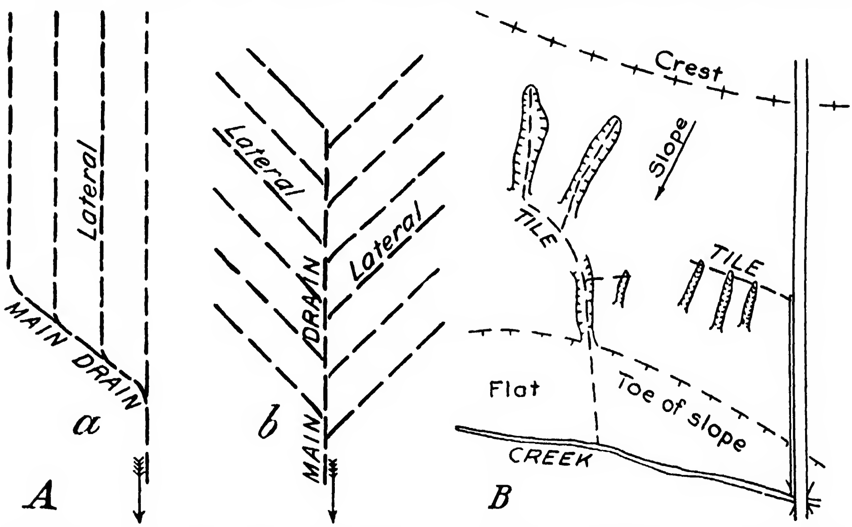

FIGURE 4.—A, Tile systems: *a*, Gridiron; *b*, herringbone; *B*, intercepting drains across heads of gullies at right and through them at the left.

There are in general two types of drainage lay-outs: (1) Drains uniform as to depth and spacing, on fairly level land, and (2) intercepting drains on hillsides. A third system called the random or natural, in which the lines follow swales, is often noted. Where more than one line is called for on account of the width of land to be drained, the design may have the characteristics of the uniform system, with long parallel laterals, or of the intercepting system, with side lines cutting off hillside seepage. A complete understanding of the possibilities of the various systems will often result in great economies in the first cost and in more successful operation of the drains.

Running a long main with a number of short stubby laterals, usually called a herringbone system (fig. 4, *A*), when a few long parallel laterals connecting a short main (the gridiron system) will serve, means adding about 20 percent to the cost of the work with no added benefit, unless the double drainage along the main is needed.

Depth and Spacing on Flat Land

Much of the movement of gravitational water may be downward below the level of the tile, then horizintally toward it, and upward into the channel. In fact, practically all the water enters the tile at the joints, or spaces between the pieces, from the lower side. This is well illustrated by Schlick (*344*), who explains the capillary and gravitational movements at length. He notes the slowness of the capillary passage of water and in considering gravitational movement brings out the effects of soil channels, temperature, barometric pressure, texture, and structure. In a general statement of results he says:

> These investigations and studies indicate quite clearly that, in the average loam soils of Iowa, laterals not to exceed 100 feet apart will be required to accomplish this [proper control of ground water] and that the increase in crop production when laterals are not to exceed 75 feet apart will very probably make such a system economically desirable.

(The economic conditions were those of 1918.) Wider spacing is recommended for open soils and less for hardpan. He continues:

> When thoughtful consideration is given to all factors, there seems to be no adequate reason why the average depth of all lateral systems should not be at least four feet [with possible exceptions for hardpan].

These figures are for a permeable soil. Tighter soils would take too long to drain if these measurements were used. Experience in a particular locality is necessary to insure the best results.[3]

Schlick (*345*) reported laboratory tests on a fine sandy soil and developed a formula for the curve of the ground-water table between drains. He checked the fact that the water entered the joints of the tile at the bottom, and the hydraulic head in a gage pipe under the tile was found equal to that at the same horizontal distance from the drain. In a black loam topsoil, high in organic matter, results indicated that "organic and colloid content may be important factors in the rate of the movement of water through soils."

Laboratory tests will always be a definite check as to the uniformity of the drainage properties of the soil samples tested, but in actual practice the action of the drains over a period of years, the effect of improved soil structure, plant roots, temperature and barometric changes, the incorporation of lime and organic matter, and possibly other influences, will all tend to make field experience in successful projects the best guide. Jones (*190*) suggested that studies of actual systems form the basis of economical design. His Tunes of Tom the Tiler (*191*) covered practically the entire subject of drain-

[3] Neal (*276*) has developed a method of determining tile spacing and depth, based on soil characteristics and constants, which is said to be so simple and effective as to be readily applied by the agricultural engineer. "Nomographs," or diagrams, with three variables, are given for two methods—the plastic consistency and the clay content. These two diagrams are based on a fall of 1 foot per day in the ground-water table at a point midway between the tile lines. For other rates he gives a linear diagram or nomograph that should prove very helpful when mastered. The same information has been given in a popular bulletin (*315*), with suggestions for use in the field.

age in pleasing verse, and the footnotes gave considerable history of drainage.

In Missouri, on Boon County bottom land, which responded readily to underdrainage, Johnson (*188*) reported a spacing of 300 to 350 feet between lines and a depth of 3½ feet as satisfactory. The drained portions produced good crops for 5 successive years, while the undrained part of the field had only two crops out of five. The tile paid for itself the first 2 years and permitted work 2 weeks earlier each season.

Most of the information on depth and spacing applies to ordinary farm crops. Naturally alfalfa with its deep roots could use the deeper drainage, with corn next. Wheat and small grains would stand more shallow drainage. A depth of 3½ feet in a sandy loam (Sassafras) proved good for potatoes at a spacing of 100 feet, but the crop midway between lines 120 feet apart was poor. On the other hand, tomatoes and other truck crops in the same soil would probably do better with the lines closer together and placed at a depth of only 2 feet. Much depends on the demands of the plant for soil moisture as well as the root depth. Four feet is usually considered a fair depth for orchard drainage.

Peat and muck soils offer many variations as to depth and spacing. Alway (*11*) holds that the spacing of laterals depends—

> partly on the character of the peat, but more upon the rainfall . . . heaviest yields have been obtained where the water was not more than from 20 to 40 inches below the surface.

To achieve this depth of the water table over most of the area, tile would have to be roughly from 3 to 4 feet deep.

In his bulletins on various truck crops on muck soils in New York State, reference to the one on lettuce being the only one given here, Knott (*200*) notes the advantages of rapid drainage in the spring with a depth to the water table of 18 inches, which may be later increased to 2 or 3 feet. The recommendations are the same for other truck crops. However, if the level rises later in the season, growth is checked and yield is reduced. B. S. Clayton noted in Florida that a similar rise in the soil water table at the end of a dry season seemed to produce serious crop injury owing to the fact that the stagnant water had absorbed from the soil certain toxic materials injurious to the plants. He used drains 15 feet apart, while Knott reports that the truck growers included in his studies had an average spacing of 60 to 75 feet. In the 1935 annual report of the Florida Agricultural Experiment Station (*110, p. 102*) the statement is made:

> When once dry, these peat soils can never be restored to their former volume . . . A program for the conservation of soils in the Everglades must include the maintenance of a proper water table.

Practical considerations indicate that in order to protect tile from crushing and to prevent suck holes from the surface down to the joints between the tile there should be an ample covering of earth. In the case of 4-inch tile, this is usually provided by laying them at least 30 inches deep. For larger tile a good rule is to have at least 2 feet of firm soil over the tile, but where heavy machinery is to be used it may be better to go deeper.

Intercepting Drains

Intercepting drains tax the ability of the tiler to catch the water more than any other type. Springy spots or seepage areas, in some localities also called "spouty" places, may be caused by a number of factors. A layer of clay or hardpan often causes the water to come to the surface. A change in the slope of the ground surface will have the same effect, and beds of porous material, such as gravel (fig. 5) or sandstone, may contain water that must be tapped if the system is to be a success. The gravel in figure 6 did not appear at the surface, and in such cases, many people are surprised at the failure of the water

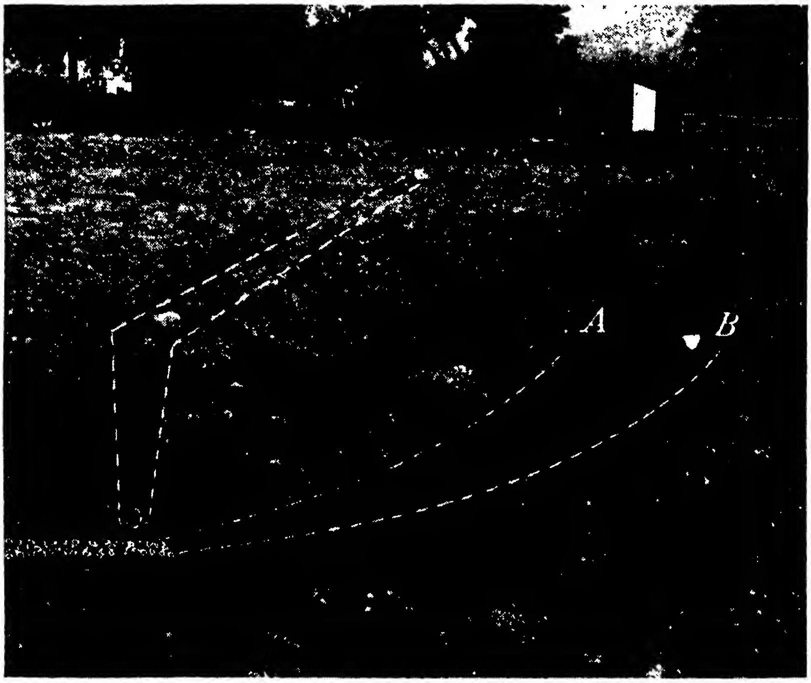

Figure 5.—An unsuccessful intercepting drain of 4-inch tile laid across the slope to main in background. A bed of water-bearing gravel was 6 inches below the tile and free water collected in the holes *A* and *B*, 14 feet downhill from the tile.

to rise into the tile rather than appear at a higher elevation downhill. Such a condition as the one illustrated is not unusual when drains are placed at too shallow a depth on a hillside. In similar instances, boring holes with an auger into the water-bearing strata, a method devised by John Elkington, an Englishman, in the eighteenth century, has been known to let the water rise into the drain.

Lines across the slope seldom have much influence on the land above them, since they act as intercepting drains. Occasionally, however, when intercepting tile lines have been laid in very loose soils, water has seeped out of them along their lower portions after having been

collected into the tile, from saturated soils at the head end. The water could run through the gravelly soil easier than in the tile lines which were laid on a very flat grade. Thus part of the seepage, which the drains were supposed to correct, still persisted to a greater extent in the land adjacent to the lower part of the drain. Chamberlain (*63*) has even noted instances where small tile systems have been emptied into gravel banks, some having worked for 30 years. This would not give as free flow from the tile as an open outlet, and would restrict the aeration of the soil.

Intercepting drains have been used at the heads of gullies to cut off seepage water that had been largely responsible for the gullying. This may occasionally be done by a tile line across the slope away from the gully (fig. 4, *B*). Sometimes, however, the discharge line must be taken directly down the hill, and it is desirable to keep the ditch line to one side of the gully bottom to keep the tile from washing out before the filling is complete or has become compacted.

A fair rule to follow in locating intercepting lines is to put the tile line up the hill crosswise of the slope, about a rod above where the water shows, and dig deep enough to cut the water off. The line leading the water away may have to go directly down the slope after the seepage is tapped. A drain directly up the hill into a spring may not catch all the seepage unless it branches out each way above the spring to form cut-off lines across the slope.

Mole Drains

The use of a heavy colter, to which is attached a steel mole, ball, or bell, to form an artificial channel in the soil for drainage purposes, has been attracting more or less attention for a number of years. The drains seem to work well in Europe, and there have been good results in a few places in this country. The main objection to their use is lack of permanence. Robey (*311*) after tests in five counties in Michigan in heavy clay found they had practically no effect on the water table. Many filled with soft mud over one winter.

It has been suggested that mole drains may be used as an adjunct to tile lines to break up a hardpan, using the tile as outlets for the moles. This would seem to place the tile in danger both from crushing by the mole and from silting with soil washed into it from the mole drain. However, if the mole drains can start at a ditch bank, in a road cut, or on a hillside steep enough to let them work in to a depth of 2 feet without any dips so there will be a free flow, they may last a few years and give satisfaction. More work is being done in studies of mole drains.

Mole drains are advocated for heavy soils that usually run together if they are worked while wet. When dry the soils would be too hard to draw the mole enough. The "very smooth surface" on the wall of the mole drain reported by Robey (*311*) may very probably have had some adverse effect on the percolation into the drain, due to the soil being packed and polished to a tight wall surface, practically impermeable except through the colter cut.

In 1929 mole drains were suggested for the Everglades in the annual report of the Florida Agricultural Experiment Station. B. S. Clayton reported in 1935:

Under-drainage by mole lines is practical in Florida peat lands. Mole lines are installed by drawing a 6-inch steel cylinder through the ground at a depth of about 30 inches. The lines usually are 15 feet apart. Mole lines fill with sludge eventually, but some are still open after 5 years of use.

Water tables are held at the highest elevation consistent with plant growth and maintained at as near a uniform elevation as possible. High water tables prevent excessive settling of soils. It is generally believed the water table for sugar cane should be somewhat higher than for truck crops.

Successful gravity drainage is not possible because of the flatness of the land. There is better control of the water tables if low-lift pumps are used with open ditches for mains (*192*).

Deep knifing may help break up a hardpan, but if it is done when the soil is too moist it may do more harm than good. In some instances the broken subsoil has let so much moisture pass that the crop has suffered from drought.

Design of Systems

The cost of construction is often more of a guide in laying out a drainage system than the optimum drainage desired. When a 4-foot

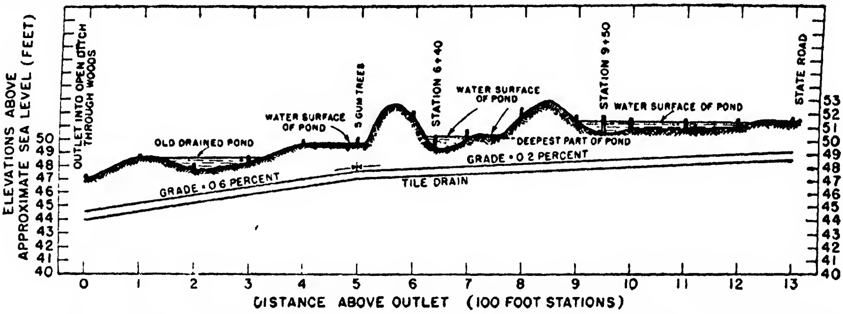

Figure 6.—Profile of tile drain illustrating grade to reduce cutting through ridges to drain five ponds. This line cost $500, but a bank official stated that it increased the value of the farm more than double that amount.

ditch costs almost double one 3 feet deep, it is easy to understand why drainage a little too shallow is sometimes installed, particularly where the work must be done by hand. Partial drainage is often worse than no drainage at all, since it tempts the farmer to plant where the success of the crop is doubtful.

Of course such practical considerations as the available outlet, minimum grades, desired depth, and source of water all enter into the design.

The profile of a rather crooked, random line 1,300 feet long (fig. 6) brings out some of these points. A true grade from the outlet to the head would have increased the 5½-foot cut through the ridge at least another foot. The 4-inch tile at the head of the drain had ample capacity on the minimum grade at 0.2 percent adopted. With machine work, a much flatter grade may be used, but unskilled labor can rarely do a good job with less fall than 0.3 foot in 100 feet.

Persons not skilled in drainage practice often fail to break the grade as illustrated, placing the tile far deeper than necessary through the ridges and then bringing it to the surface in the pond bottom. The cover in two of the five ponds shown on the profile was less than the 2-foot

minimum previously given. However, moving some soil by plowing toward the low places in the ponds raised the levels to a safe point.

There is usually so much fall on hillside work that intercepted water can readily be led away without recourse to minimum grades. This is fortunate, for the water-bearing strata must be tapped. The matter has been tersely summarized by the late C. G. Elliott (*102*) as follows: "The best success in draining cannot always be secured by following either a plan or a gradient which looks good upon paper."

Silt wells, or basins below the grade line of a tile drain intended to impound sediment seeping in with the ground water, are seldom needed except in theory, but they may be combined with surface-water inlets in low places to good advantage. It is best to place such a structure in a fence line, if possible, out of the way of farm operations.

Tile less than 4 inches in diameter is seldom recommended for laterals. In muck soils this is often increased to 5 inches with good results.[4]

After the main is decided upon, branch lines may be located in general according to the suggestions already given. Many valuable points can be found in some of the popular references already noted and in similar publications. It is not the intention in this article to go into the engineering aspects of the subject.

Methods of Installing Tile Drains

Methods of constructing open ditches and mole drains have already been noted. There are several essential points to be considered in laying tile.

The ditches for tile should be dug as straight as possible with easy curves at any change in direction. Hand tools, ditching plows, or machines digging to full depth at one cut may be used. The latter can be had in types that leave a smooth bottom ready to receive the tile.

The quality of the tile can readily be determined by examination of materials locally used in successful systems, or from the Standard Specifications for Drain Tile of the American Society for Testing Materials (*12*). It should be remembered that there is nothing to the old idea that porous tile make drains operate better. The denser the tile, the more durable they are. They ought to ring when struck.

The tile should be placed on a firm, well-graded ditch bottom. If the bottom is soft, boards may be first bedded on grade. In most instances it is desirable to butt the adjoining tile together, touching at the top. Round tile can be turned in the trench until they touch on the upper side.

Some farmers prefer to leave a slight space, about the thickness of the spade blade, between the pieces of tile. Experience proves, however, that this can do more harm than good because fine sand seeps in. Tile laid with a space between each piece have ceased to function

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[4] The main lines can be designed best, by those who understand the matter of run-off, through the use of the formula developed by the late D. L. Yarnell (*473*), and also given in the popular Farmers' Bulletin (*192*). It is:

$$V=138\ R^{2/3}\ s^{1/2} \text{ (the cube root of } R^2 \text{ and the square root of } s\text{)}$$

where V is the velocity, R the hydraulic radius, and s the slope. The tables in the latter reference may be easier for some to use than the diagram in the professional paper.

after 50 years. There was no earth in the tile, but the tight soil had sealed the joints. It is possible that if some topsoil containing organic matter had been tamped around the sides and top of the tile (this is called blinding) they would have continued to operate satisfactorily.

The efficacy of blinding with topsoil is open to argument. Chamberlain (*63*) preferred to shave moist clay around the tile and lightly pack it into place to make the water enter the bottom. His procedure has been recommended for quicksand. Theoretically, the organic matter in topsoil will rot and in settling cause suck holes, but in practice it has helped many tile lines to operate in soils inclined to seal the joints. The tile at the left in figure 7 were ready to be blinded at the time the photograph was taken, and the rough fill was made when the entire line could be plowed or scraped at one operation. With hand work it is always desirable, as one drainage authority has said, to "dig, lay, and back-fill as you go." Practically all experienced drainage men work uphill from the outlet.

Figure 7.—Y branch at a tile-drain junction. Tile touches on top at the joints. Piece at the right was left standing on end overnight to prevent entry of trash and animals into the drain.

Such matters as transferring the grade of the survey, if one was made, to the ditch bottom, closing the upper ends of lines, and protecting the outlets in a substantial manner are all standard practice and need no mention here. Care in laying the tile is the place where "eternal vigilance is the price" of success. The unskilled workmen who merely bury tile instead of constructing a drain are the ones who cause the farmer to waste many hard-earned dollars. The work is expensive, and drainage is often difficult to install. If tile could be spread like lime or fertilizer there would be no wet spots. Yet there are many farmers who say: "The tile drains are the best investment I ever made."

IN THIS ARTICLE the authors describe how forest soils are formed; show how unwise cutting, forest fires, and overgrazing all have harmful, sometimes disastrous, effects on these soils; discuss some general principles involved in maintaining the soils in good condition, and in building up new forests rapidly; and show that the need of reforesting in the United States is increasing faster than the job is being attacked.

Management of Forest Soils

By IVAN H. SIMS, E. N. MUNNS, *and* JOHN T. AUTEN [1]

IN THE BEGINNING forest soils were the most extensive natural resource in this country. For 250 years the expanding Nation pushed through forest cover and onto forest soils. Today only a little over 10 percent of the original 820 million acres of forest remains uncut, and the larger part of this has been subjected to one or more forms of use or abuse.

CHARACTERISTICS OF VIRGIN FOREST SOIL

The obvious, outstanding features of forest soils are zonation into marked horizons, stability, porosity, light weight, moderate organic-matter content, large animal populations, dependence on the forests they support, and the ease with which they can be altered,. lost, or destroyed under bad practices.

Forests can exist only where rainfall and temperature exceed certain minima and before being disturbed were to be found practically wherever these minima were exceeded. The limits between the humid and the semiarid and arid regions are largely defined by the presence or absence of natural forests. The soils of the humid regions—the Podzols, Gray-Brown Podzolics, Red and Yellow Lateritics, and the Laterites—are forest soils.

The structure, zonation, and chemical condition of undisturbed forest soils is clear evidence of their stability. Neither the leached Podzols and podzolic soils nor the hydrolized colloids of the Laterites and lateritics could have developed except where the soil was held in place for long periods of time. Both podzolic and lateritic soils, more-

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over, reflect the porosity of forest soils, their formation being dependent on the presence of abundant moisture. A compact, dense soil would preclude the entrance or passage of water, without which neither leaching nor hydrolysis could occur.

This porosity, in turn, is dependent on several other conditions and processes, the presence of large amounts of vegetable debris, the activities of a large population of fungi, bacteria, and minute animals, and the penetration of the soil by the roots of trees and lesser vegetation.

Organic matter incorporated into soil is responsible for certain desirable characteristics. It is usually associated with high nitrogen

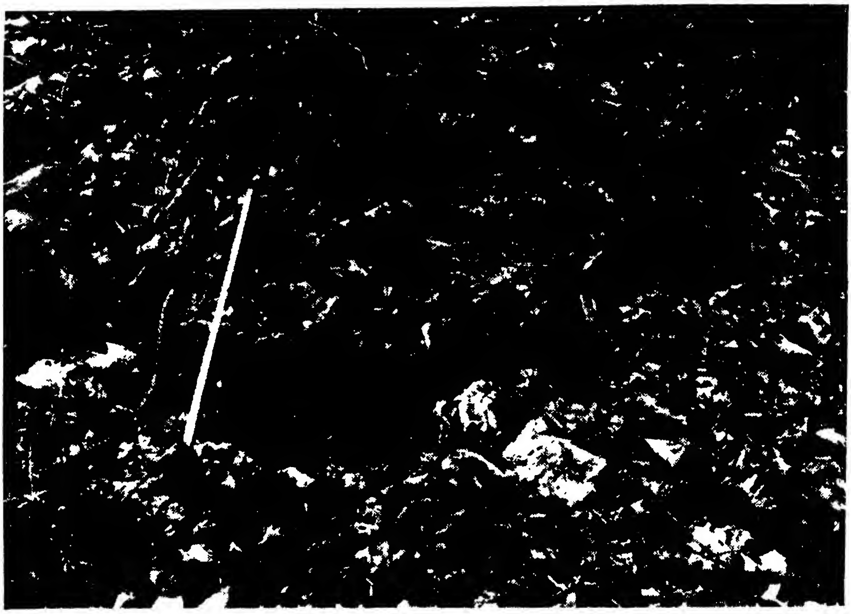


FIGURE 1.—Forest cover returns large quantities of organic matter to the soil each year.

content, high content of exchangeable bases and high base-exchange capacity, flocculated structure, good tilth, and light unit weight. Most of the desirable effects of organic matter, moreover, are known to depend on its presence in colloidal form. The forest community is especially well organized not only to provide an abundant supply of organic material but also to reduce it to colloidal form and effectuate its incorporation into the soil itself.

Each year from 1½ to 3 tons per acre of dead leaves, twigs, branches, and tree trunks, collectively known as litter (fig. 1), are deposited on the forest floor by a dense stand of trees, and a large number of roots in the soil die. This material is rapidly consumed and converted to colloidal forms, and except in the colder parts of the country,[2] the

[2] The spruce forests of the North and the high western mountains have accumulations of organic debris often a foot or more in depth.

total accumulation of such litter on the forest floor is seldom more than three or four times as much as the annual deposition.

Reduction of the litter to humus is effected by the fungi, bacteria, and animals that live in and on the litter and soil. The primary attack is by wood-rotting fungi and such vegetarian animal forms as termites, ants, larvae of larger insects, earthworms, millepedes, and mites. In the wake of these primary attackers come other organisms that eat them, their offal, what is left of the litter, and each other. The fineness of the resulting material can be visualized by considering that many of the species of animals with chewing mouth parts are only one-tenth of a millimeter (one two hundred and fiftieth of an inch) broad.

In the soil itself a similar population converts the dead roots and rootlets and the organic matter brought down from the litter layer

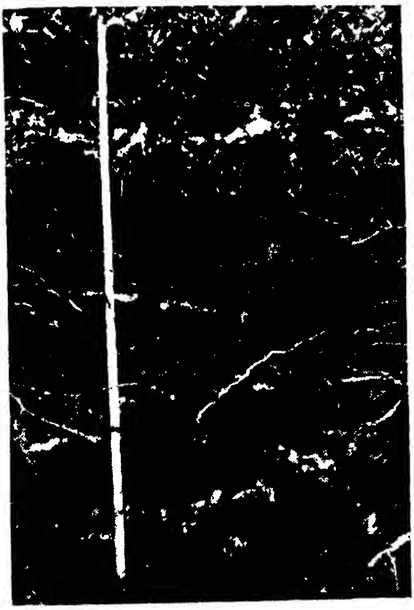


FIGURE 2.—Soil under an uncut forest is friable and porous, deeply penetrated by roots and infiltrated with organic matter.

FIGURE 3.—Soil profile from heavily cut area; surface layers have become compacted and have lost much of their organic matter.

Their burrows and tunnels, although averaging only a millimeter in diameter, contribute in large measure to the lightness and porosity of the soil.

The small size of these useful animals is compensated for, however, by their numbers. Partial catches obtained with special equipment show as many as 5,500 individuals (not including earthworms and nematodes) per square foot of soil to a depth of 13 inches. As many as 70 different species have been collected from less than a square foot of rich forest soil. The total animal population of the soil and litter together probably approaches 10,000 individuals per square foot.

The humus produced by this vast population is extremely rich in plant nutrients, for the nitrogen and important bases are all conserved in the process of transforming the litter to colloidal organic matter. Much of the fertility of forest soils, the lateritics for instance, is due to the incorporation of humus into the mineral soil. The best soils show a gradual decrease in humus from the surface downward, with the lower limits as deep as 2 or 3 feet (fig. 2). Where animal population or activity is low, as in the Podzols of colder climates, conversion is slow and the litter and humus are not mixed with the soil but lie as a mat or turf on its surface. Under such conditions the mineral soil is usually lacking in fertility.

The relative fertility of the different soil layers is indicated by the number of roots present, for it is well known that roots divide more frequently and grow more rapidly in fertile soil than in infertile soil. In a vertical cross section there may be as many as 1,200 roots per square foot in the humus layers of the litter but only a dozen or so near the lower limit of humus penetration into the soil. This concentration of roots in the surface layers is highly important in stabilizing forest soil. Where organic and mineral horizons are not well mixed there is frequently a heavy concentration of roots in the lower litter layers.

The forest, then, is more than a mere collection of standing trees. It can be seen as a community of very active organisms, well organized, interdependent, and delicately balanced while following a definite line of development. And as in other organizations, interference with or elimination of any part of its function will change the whole course of development or even threaten its very existence.

PAST TREATMENT AND MISTREATMENT

The forest soils of this country have received no management in the sense of conscious guidance of their development or their conservation. Interest has been centered in the trees, and the basic resource, the soil, has received little or no constructive attention. Such treatment as forest soils have received has been in connection with forest cutting, fires, grazing, and clearing for agricultural use.

Timber Cutting

Cutting of the forest is potentially the least harmful of the treatments applied to forest soils. It is susceptible to strict control as to time, place, and intensity and hence provides a method of managing the composition and completeness of the forest cover. The extent and intensity of soil changes brought about follows rather closely the severity of the cutting.

In the past, cutting has been subjected only to economic restrictions. Lumbering was largely a process of liquidation, and hence complete removal of the forest was all too common. The earliest cuttings were very light, approximating natural processes in the undisturbed forest where scattered overmature, diseased, and injured trees die and are immediately replaced by new ones. Openings in the cover were small, and a continuous litter cover was maintained on the soil. The subsequent development of the lumber industry led to more and more

severe cutting, finally culminating in the clear cutting of all merchantable trees.

At just what degree of cutting deleterious effects on the soil first occur is not known. It probably varies in different types of forest, but the effect on the litter cover probably provides a good criterion. The safe limits have very likely been exceeded when the litter is consumed more rapidly than it is replaced and its continuity is broken.

Sharp reduction in the rate of litter deposition is not immediately followed by reduction in soil and litter populations. There may even be an increase in the rate of reduction induced by higher surface temperatures in the openings. Sooner or later, however, the litter layer under heavily cut stands is reduced in thickness until it no longer affords adequate protection for the soil. Drying out and compaction (fig. 3), reduction in population of soil organisms, oxidation of humus, and erosion soon follow.

These effects are minimized when cut-over areas regenerate promptly with tree species or are invaded by herbaceous vegetation. Sprout growth from hardwoods doubtless provides the quickest regeneration, but it is not sufficiently rapid to prevent some of the bad effects. A watershed study conducted at Wagon Wheel Gap in Colorado provides an illustration. After the behavior of a stream from a forested watershed had been observed for 9 years, the cover, largely aspen, was removed. The stumps and roots sprouted profusely, but in spite of this the silt load of the stream increased seven and one-half times and the water lost to the soil as run-off also increased. Decreased soil porosity was further shown by a 58-percent rise in the height of flood crests following cutting.

Examples in this country of serious soil deterioration due solely to removal of the forest by cutting alone are rare, but heavily cut areas are commonly burned over shortly after being lumbered and the burning is generally responsible for the bad effects following logging. In Europe, however, repeated clearing and planting of spruce led to serious impairment of soil fertility as measured by the growth rate of the forest. How much of this was due to changes in the litter is problematical, for the system of silviculture eliminated hardwoods known to have a favorable effect on the soil.

Fire

Heavy cutting has commonly been followed by fire, and examples of serious soil deterioration due to this combination of treatments can be found in practically every forest region of the country. Some 60 million acres of land have been so completely devastated by this combination that they are unlikely to reforest naturally and must be planted. The total is being swelled currently by the addition of 850,000 acres each year, three-fourths of which is land formerly occupied by conifer stands.

When cut-over land is burned the fire accomplishes in minutes the degree of litter removal that would be achieved naturally only after several years (fig. 4). This sudden removal of the litter and its living population sets in motion a chain of events leading directly to deterioration or loss of the soil. The highly alkaline ash is leached or carried into the soil with the first rains and there acts to defloccu-

late the soil granules made up of silt and clay particles. The dispersed soil particles, readily taken into suspension by falling rain, are carried into the soil channels and clog them, and surface run-off and erosion begin immediately. Loss of the surface soil, reduced infiltration of water, and desiccation rapidly reduce the soil populations. At the same time increased soil temperatures result in rapid oxidation of humus, still further reducing the fertility already impaired by loss of nitrogen during the fire.

On light sandy soils of low gradient the processes are similar except that erosion is not a factor. In its stead the essential bases are

Figure 4.—Severe fires leave the soil completely barren and subject to severe erosion.

leached deeply into the soil and in effect are lost. The organic matter, the soil and litter organisms, and the nitrogen disappear just as completely as though washed away, and the surface layers are left in a sterile condition unsuited to the establishment of a new forest. Outstanding examples of the results are found in the pine plains of the Lakes States, the Cape Cod section, and the pine barrens of New Jersey.

This chain of events occurs in a relatively short time, a matter of months or at most a few years, and the invasion of the area by grass or herbaceous vegetation seldom occurs quickly enough to arrest it. The relations between the soil, the vegetation, and the soil life, moreover, are so definitely different under herbaceous and forest cover

that the soil organisms characteristic of one are not found under the other. The longer the period between devastation and reforestation the greater is the change in the soil from its original condition.

The type of vegetation likely to occupy an area following cutting and repeated fires differs widely among the regions. California pines are followed by brush species collectively known as chaparral, southern pines are replaced by grasses and scrub oak; in the Lakes States sweetfern and bracken spring up; and in the Appalachian Mountains ericaceous shrubs and scrub oak invade hardwood lands.

Even though not accompanied by cutting, forest fires are a major factor in the degeneration and destruction of forest soils. They vary in intensity from the spectacular holocausts that destroy the forest completely to the innocuous-appearing leaf fire that consumes only part of the litter. The seriousness of their effects on the soil varies accordingly.

Extreme soil temperatures frequently develop during the great conflagrations and humus in the upper horizons is oxidized immediately. The mineral soil has much the same appearance as samples ignited in a furnace. Accumulations of heavy debris burn with such intensity that the soil is sterilized for years. Examples have been observed where tree reproduction has failed to become established on such spots more than 10 years after the fire.

Similar conditions have been observed where slash piles have been burned following logging operations.

In southern California, chapparal-covered mountains are often completely denuded by fires. The denudation is followed with predictable certainty by floods carrying tremendous quantities of eroded soil and debris from the steep slopes. One such flood following a 10-inch rainstorm removed 67,000 cubic yards from each square mile of denuded canyon. An adjacent unburned canyon, similar in topography and subject to the same storm, lost but 50 cubic yards of soil per square mile.

Following the great conflagrations of 1910 and 1919 in the forests of the northern Rocky Mountains observers have reported the loss of as much as 5 inches of topsoil over extensive areas.

The sequence of events and the causal relationships leading up to these spectacular and catastrophic losses are operative to a lesser extent wherever forest fires occur on sloping land. The rapidity with which the chain of events takes place and the point at which they are halted depend on the degree to which the protective litter and trees are removed. What may be considered the typical fire, both in hardwoods and conifers, removes the litter completely, kills all shrubs and small trees and a few of the mature ones, injures others of the larger trees, and kills the surface roots of all vegetation. Replacement of the litter begins with the next leaf fall and the original condition is approached in some 5 to 10 years. Meanwhile the soil has been subject to compaction, more or less erosion, increased desiccation and oxidation, and sharply curtailed biological activity. Little is known about the rate at which recuperation takes place or the time required for the soils to regain their original condition.

The degree to which soils become compacted following forest fires is shown by the results of an experiment conducted in hardwood

stands in the Central States. Water was applied to both burned-over and unburned soils and the rate of absorption per second was measured. Undisturbed soil absorbed the first application three to four times as rapidly as the burned soil. The fourth successive application was absorbed by the unburned soil 6 to 10 times as fast as by the burned.

Grazing

Grazing has the same ultimate effect on forest soil as fire and heavy cutting although the rate of deterioration is slower. Just as very light cutting may produce no visible or measurable effect, so very light grazing may cause no significant changes. On the other hand, overstocking of forest ranges and pastures leads to dangerous conditions within 10 to 20 years and in extreme cases in shorter periods (fig. 5).

FIGURE 5.—Patchy litter, compacted soils, and absence of small trees characterize the grazed woodlands of the Central States.

But if the rate of deterioration is low it is more than compensated for by the extent of the practice. Nearly three-fourths of the present forest area of the country is grazed each year—144 million acres in the West, 149 million in the South, and 42 million in the Eastern and Central States. Grazing usually is not coordinated with other uses and requirements of the forest, and overgrazing is common. The number of livestock grazing the farm woods in the Central States is estimated to be five times the actual carrying capacity and is maintained largely by supplementary feeding of crop feeds.

The effects of overgrazing in hardwood stands show up first in the thinning of the understory of small trees and low vegetation, perceptible thinning of the litter layer, compaction of the upper soil lay-

ers, and destruction of the surface network of fine roots. In later stages regeneration of the forest is prevented, older trees become unthrifty and die, the stand is progressively thinned, and the forest is eventually converted to grassland. Concurrently the soil changes from one typical of forests to a grassland type. Heavily grazed soils have been found as much as 15 percent heavier than those from ungrazed forests. The more compact condition of overgrazed woodland soils is demonstrated, moreover, by increased run-off from rains and greater erosion losses. In Wisconsin soil losses were nearly 100 times as great and water losses 60 times as great from a pastured as from an unpastured wood lot. The proportion of these losses due to compaction and that due to decreased litter depth is not apparent. In the Central States the litter under grazed woods (0.4 inch) was found to be only a quarter as deep as under ungrazed forest (1.8 inches). The difference in thickness of the humus layer was even greater.

In the West the vicious cycle of depletion of vegetative cover, soil compaction, increased run-off, increased erosion, reduced fertility, and deteriorated vegetation has been traced to overgrazing on brush-covered and forest land, although the effects generally were not as severe as on grassland. An extreme example, but one illustrating the point to which the process may progress, may be cited from the Wasatch Mountains of Utah. A series of floods from small canyons spread thick deposits of mud and rock over rich agricultural land at the mouths of the valleys, damaging land, buildings, and other improvements to the extent of $1,000,000. Investigation showed that the concentrated run-off responsible for the floods originated on comparatively small areas of barren, compacted soil high on the canyon watershed. Moreover, the denuded and compact condition of the soil was shown to be directly due to destruction of the original tree and brush cover by overgrazing. Expensive terrace-trench construction was necessary as an aid to revegetation of the areas.

Forest ranges have commonly been burned repeatedly by stockmen in the belief that the quantity and quality of forage was thus increased. The effects of these fires have been cumulative and have seriously reduced the productivity of the forest. In the tension zone between the forest and grassland in California, cutting, grazing, and fire have pushed back the forest some 30 miles and 500 feet higher on the mountains. The formerly forested areas are now occupied by grass and chaparral and reforestation is extremely difficult. Many foresters believe the present unsatisfactory condition is due to loss of humus, exposure, and extreme desiccation.

Cultivation

It is not possible to determine the total amount of forest soil that has been cleared and cultivated in the United States. Census returns are inadequate, for land had reverted from cultivation to forest long before the first census of land use was taken. Pine stands more than a hundred years old can be found in New England on once cultivated land. In the South the corn and cotton rows still show in stands now being logged for lumber. In the northeast the reported area of agricultural land had begun to shrink before 1880. Even present

census figures show only the net changes between agricultural and forest use.

The maximum agricultural area for the region east of the Great Plains was reported in the 1920 census—279 million acres. During the period 1910–20, while the total reported area of cropland was increasing the sum of the losses in counties reporting decreases was 10½ million acres. During the decade 1920–30, an additional net loss of 21 million acres was reported by those counties showing decreases in agricultural land. In other counties the total agricultural land increased by 7 million acres. The census summary, however, fails to bring out the gross changes within counties, which may, of course, be material. Similar changes, though possibly on a smaller scale, have been occurring for more than a hundred years. Probably 350 million acres of forest soil have been broken for more or less temporary cultivation.

The degree to which man maintains the fertility of the virgin soil determines the period during which it can be used for crop production. Unless maintained by proper management, the fertility of the soil begins to decline as soon as the cover has been removed; cultivated soil cannot maintain itself. Without aid, soil deteriorates and the period of use for crops largely depends upon the time required to exhaust or destroy its stored fertility.

Deteriorated soils are retired from agricultural use only after they have passed the point at which artificial reclamation is economic, and such soils can be built up again only under a good cover. If not too badly deteriorated, such soils can be reclaimed for further agricultural use by the forest in from 20 to 50 years. Where deterioration has gone far, however, several centuries may be required before restoration has reached a stage sufficient to justify agricultural use again. The rate of recovery of such lands under forest cover and their future productivity should not be too highly appraised.

The point in the process of soil depletion where cultivation must cease is more apparent and generally recognized than the point at which it should cease. The "must" stage, heretofore, has been largely judged by social and economic criteria. So long as the occupants of deteriorating land could or would endure a descending standard of living, the soil was cropped. On the other hand, rational criteria for recognizing the stage of depletion demanding soil reconstruction would include the chemical, physical, and biological condition and potentialities of the soil as well as the less tangible and precise considerations of human endurance and welfare.

REHABILITATION OF FOREST SOILS

The extent to which cutting, fire, grazing, and cultivation have depleted the fertility of forest soils and caused loss by erosion is difficult to estimate. Crop yields from a given field may be used to evaluate depletion, but rate of growth and yield of the forest are useless criteria because of the understocked stands, lack of cultural treatments, and the distribution of age classes in the several forest regions. Rate of growth varies with age even on soils of equal fertility.

But if satisfactory measures and estimates of deterioration are lacking, analogies with agricultural practices, observation, and re-

search results point to the broad general lines of action needed to achieve an optimum soil condition in forested areas. Chief and most obvious of these is protection—from fire, overgrazing, and unnecessary clearing and cultivation. Equally apparent is the urgent need for reforestation of humid land proved submarginal for agriculture. Somewhat less so is the need for improved silviculture.

Silviculture

Improvement of forest soils must be achieved by indirection. The direct attack of the agronomist using such methods as plowing under of cover crops, application of fertilizers and lime, and tillage is far too expensive for wide application to forest soils. Experimentally, both in Europe and this country, such treatments have been shown to result in increased growth, but the effects have been short lived. More lasting effects can be obtained by managing the density and composition of the stands.

The agricultural principles of close-growing crops to prevent erosion and assure maximum return of organic matter to the soil, underlie, in part, the silviculturist's ideal of full stands. The incorporation of organic matter into the soil can be obtained by the forester by fostering a large and active litter and soil population, and the effects of applying lime, nitrogen, and other fertilizer elements can be achieved by regulating the composition of the stand. The essential results of crop rotation can also be achieved by maintaining mixtures of species in the stands.

The general desirability of mixtures springs from the differences in ability of the species to extract nutrients from the soil and from differences in rooting habits. As an example, the soil under a shallow-rooted pine stand in Sweden was growing steadily more acid and biological activity was decreasing; the lesser vegetation indicated distinctly poor soil. After beech was interplanted among the pines the soil acidity decreased, biological activity increased, and the composition of the herbaceous growth indicated a much higher quality site. The roots of the beech were tapping a calcareous soil layer below the zone occupied by the pine roots and returning the calcium to the litter layer. Analysis of tree leaves in the Hudson Highlands of New York indicates that even when the roots of several species occupy the same soil layers there is marked difference in their ability to extract nitrogen, phosphorous, calcium, and potassium. This differential ability, in the light of the minimum requirements of the species, goes far toward explaining the often observed successional trends in forests.

The implication is clear that species characteristic of good sites and fertile soils contribute most to the maintenance of soil quality. The species with high requirements, such as ash, maple, beech, and basswood, return large quantities of nutrients to the soil in litter. The conifers generally have lower nutrient requirements than hardwoods, and coniferous litter has lower nutrient content.

This difference in nutrient content of litter explains in part the richer and more abundant soil life generally associated with hardwood stands. This in turn accounts for the better incorporation of organic matter in hardwood soils.

The general principles by which silviculture should be guided, then,

are: (1) To maintain full stands; and (2) to encourage mixtures and direct their development along the lines of natural ecological succession.

Protection From Fire and Grazing

Regardless of the forest owner's objective, whether liquidation or sustained yield, protection from fire is a rational and economic procedure. Aside from depletion of soil and productivity, the forest cannot be perpetuated if fires repeatedly destroy the small trees. Laxity in protection exposes even mature stands to danger of destruction.

The major objective of future fire-protection activities is likely to be, as it is at present, the preservation of the trees. There is, however, no conflict between this objective and that of conserving and building soil values, and no modification of present policy is needed other than expansion and intensification.

Elimination of grazing damage to forests and forest soils will depend upon education, for the intensity of grazing is subject to control through stock numbers. Conditions and corrective measures differ between the East and the West. In the latter there are some 250 million acres of grazing land intimately mixed with forest. Some of this, moreover, is extremely good summer range at the higher elevations and is needed to supplement and round out the fall, winter, and spring forage at lower elevations.

Characteristically, livestock prefer grass and other distinctly forage species to tree browse. Limitation of their numbers to the actual carrying capacity of the forage would therefore largely eliminate the danger to the western coniferous forests. Methods for arriving at carrying capacity and for recognizing overgrazing in its incipient stage are already available. Reconciliation of conflicting economic interests involved should be feasible without sacrificing either the forest or the grazing industry.

The eastern hardwood forests present an entirely different situation. Unless cleared, the forest extends unbroken; within it grass is a rarity and such as is found is low in nutritional value. Stock perforce must browse, and tree reproduction suffers accordingly.

When and where additional pasture is needed in the East, the intelligent procedure is to clear the forest and seed the area to grass immediately. Fertility and soil are thus conserved and used. Both water and soil losses are known to be greater from grazed woodland than from cleared and well-sodded pasture.

Reforestation

The most reliable estimates available indicate that the job of reforestation is already far larger than it is possible to handle and that it is increasing faster than it is being attacked. Annual accretions of at least 1¾ million acres are being made by land abandonment, cutting, and fire to the existing total of 110 million barren acres that are not restocking naturally. Part of these new and existing barren areas will, in the course of time, reseed from neighboring stands, but this may be extremely slow. It has been estimated that some 70 million acres will remain unstocked 40 years hence. Less than 3 million acres have been successfully reforested to date.

The time required to grow a timber crop from seed has been a major stumbling block in the path of reforestation programs. The soil, however, shows definite improvement within reasonably short periods. Beneath successful plantations on good sites, litter begins to accumulate as a definite layer in 10 to 15 years; improved porosity of surface soil layers can be noted about the same time; at 30 to 40 years incorporation of organic matter in the upper soil is apparent; and at 80 to 100 years the soil has approximated the condition found under undisturbed forest. On the usual planting sites this progress may be delayed 5 years and on the poorest perhaps 15 years (fig. 6).

FIGURE 6.—Ten-year-old spruce plantation on eroded cut-over and burned land in the southern Appalachians. Forest litter and soil conditions will not be regained for many years. Closer planting with a species better suited to the site would have speeded soil recovery.

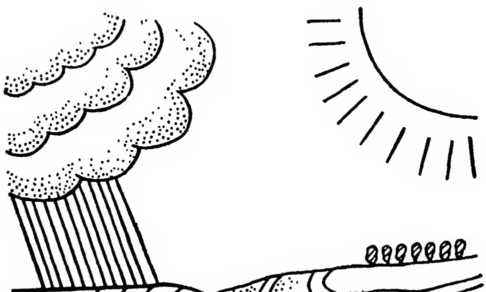
The return of forest conditions can be hastened by close planting. Where immediate control of erosion has been urgent, trees have been planted as close as 3 by 3 feet. Such close planting, however, may lead to early stagnation of growth and necessitate thinning. The use of large, healthy, well-developed stock also speeds the return to forest. Suitable coniferous nursery stock is being produced in the South in 1 year and in the Central States in 2 years, but in the North and West transplants 3 or 4 years old have given uniformly better results than the smaller seedlings.

More important, however, is the selection of the proper species to fit the site conditions. In addition to suitable climatic conditions each tree species requires that certain minima of soil nutrients, moisture, and depth be exceeded. Unfortunately, these are not as yet

well determined. A few principles, however, have been derived from past experience: Hardwoods require better sites than conifers and should rarely be planted on badly deteriorated soil; it is seldom possible or even desirable to replant the species originally present; the distinctly less desirable species from a commercial standpoint exist and even thrive under conditions submarginal for the more desirable ones; underplanting of commercial species under dense brush or under noncommercial species is useless unless followed by one or more release cuttings; where herbaceous or shrubby vegetation now occupies an area its composition and thrift is a clue to the moisture and fertility level of the site. The local application of these principles is still largely an art and is likely to remain so until accurate classification of species requirements and site quality are made available.

Part III Soils & Men

Soil and Plant Relationships



FOLLOWING the general trend of scientific development, the men investigating soils and the men investigating plant life have come to be separate tribes, each specializing in fields that have become more and more complex. But if such a division is necessary and convenient, it is also in a sense artificial, like the division between the throat specialist and the ear specialist, both of whom deal with branches of the science of medicine. The primary function of the soil, so far as human beings are concerned, is to grow plants, and the real point of all soil investigations is to discover more and more about the relationships between the plant and the soil in all of their many aspects.

This part of the Yearbook discusses some of these relationships—the soil requirements of the more important crops; the effects of the major chemical elements in the soil on plant nutrition, and on the nutrition of the animals that use the plants for food; the effects of certain other chemical elements that were not given much attention in the past but today are increasingly seen to be very important in many cases; the special problem of the effects of selenium in soils; and the association of broad types of native vegetation with soil series, which often makes it possible to diagnose certain soil conditions by observing the native vegetation.

THIS ARTICLE gives six conditions that are essential if the soil is to be suitable for the growth of crop plants. Some of these favorable conditions can be brought about, under certain circumstances, by management practices; others must be inherent in the soil. Following a brief discussion of these general soil requirements, the article takes up the important crop plants in alphabetical order, describing the soils most suitable for each.

The Soil Requirements of Economic Plants

By M. F. Morgan, J. H. Gourley, and J. K. Ableiter [1]

IF A SOIL is to compete successfully in the production of an economic plant that is climatically adapted to a given region, it must provide, either naturally or by economical adjustment, certain favorable conditions.

SIX ESSENTIAL SOIL CONDITIONS

The fundamental requirements of crop plants as to soil condition may be summarized as follows:

(1) Suitability for the cultural implements required for most efficient production; (2) effective resistance to destructive soil erosion or soil depletion under the cropping system involved in profitable management; (3) adequate moisture storage to meet the water requirements of the crop, under normal rainfall or irrigation; (4) adequate aeration to a suitable depth to permit the development of a favorable root system for the mature plant; (5) available plant nutrients sufficient for profitable yields; and (6) freedom from adverse chemical conditions such as harmful concentrations of soluble constituents, and from other special soil conditions that favor the development of organisms parasitic to the crop.

The prevailing topography, or lay of the land, associated with a given soil is often the determining factor in its suitability for crops, with respect to both cultural operations and soil erosion. The undesirable physical properties that make the tillage of intractable clay soils very difficult are often an effective barrier to their profitable utilization. The prevalence of tillage-impeding boulders throughout many soils places them under a handicap that cannot be surmounted

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under present labor costs. The peculiar erodibility of certain silt loams and very fine sandy loams, such as those developed on the loessial deposits of the Mississippi Basin, operates against their long-time use for many valuable cultivated crops to which they are otherwise adapted.

The third requirement, adequate moisture storage, while capable of direct modification by irrigation, is not possible of fulfillment on great areas of excessively sandy soils, or in vast regions where there is no available source of irrigation water. The supply of both water and oxygen for plant roots is determined by several conditions of the soil, such as texture, structure, and depth to the water table. These may be grouped together for convenience as the moisture relationships of the soils. They, in turn, are of almost equal importance in determining the chemical status of the soil, since they are factors in microbiological activities influencing nitrogen transformation, sulphofication, oxidation, carbon dioxide production, etc., rate of solubility of the constituent soil minerals, oxidizing or reducing conditions, and the degree of concentration of dissolved substances.[2]

The fourth condition, adequate aeration, is precluded in many soils with a water table near the surface, or with heavy, impervious subsoils that cannot be drained satisfactorily. In many regions well-drained, suitably aerated soils, with mellow or friable subsoils overlying porous substrata, are available, and the waterlogged soils are relegated to native vegetation or to the low-grade grazing provided by certain grasses and sedges that withstand such a condition. On the other hand, many soils with only slightly imperfect aeration seem to be satisfactory for a time, but in seasons of especially heavy rainfall, or with increase in the age of the growing plants and consequently greater root requirements—as with orchard fruits—they prove to be unsatisfactory.

The fifth requirement, an adequate supply of plant nutrients, is adjusted most readily. The chemical condition of the soil as a requirement for plant growth involves its ability to supply adequate amounts of available nutrients to meet the needs of the plant during all periods of growth, without permitting the development of harmful concentrations of any constituent. The decreasing relative cost of fertilizer materials and the growing scarcity of soils that give profitable yields without added nutrients both tend to minimize the unfavorable economic situation of a chemically "poor" soil. It is still true, however, that a truly fertile soil requires a comparatively small investment of fertilizer for the growing of the common farm crops.

The sixth condition, freedom from adverse chemical conditions, is also largely subject to intelligent control. For example, excess salts may be leached from the soil and harmful alkalinity corrected by the application of gypsum or sulphur, provided plentiful water and adequate drainage can be supplied. Adverse acidity may be overcome by liming.

[2] Many efforts have been made toward the isolation of a single soil characteristic that defines the moisture status of the soil. The "moisture equivalent" measurement developed by Briggs and McLane (*46*)[3] while empirical in character, appears to be a reasonably satisfactory basis of comparison since it represents a fairly approximate weighted average of the influences of soil texture, composition of soil colloids, humus content, and soil structure. Thus, when existing conditions of soil moisture are considered in relation to the moisture equivalent, the degree to which the soil maintains a deficient, favorable, or excessive moisture condition for adequate plant growth can be determined. This is well illustrated by the studies of Conrad and Viehmeyer (*76*), Lunt (*224*), and others.

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

Injurious plant diseases or root parasites that are related to soil reaction or drainage condition may be avoided in part by good soil management. The cost of such steps, however, may place such ill-favored soils in an adverse position in competition with more suitable ones.

Conditions of favorable physiological balance must be provided. The ability of the plant to absorb a basic constituent is modified by the quantities of other bases active in the soil. Thus, magnesium is less available in a soil containing large amounts of active calcium and potassium, and the intake of potassium may be insufficient if calcium or magnesium is disproportionately high. Some plant nutrients utilized in large amounts, such as the nitrate ion, may be distinctly harmful in excessive concentration; others, chiefly boron, zinc, and copper, although definitely required in minute amounts, produce toxic effects at relatively low concentrations. Others, such as thallium or selenium, have never been found to be of any benefit and are extremely poisonous when any appreciable amount is present in the soil solution.

The reaction (acidity or alkalinity) of the soil is an important factor influencing plant growth either directly or indirectly. Under strongly alkaline conditions, harmful effects accompany the development of excessive amounts of alkali carbonates. In very acid soils there may be injurious concentrations of certain constituents, such as aluminum and manganese, that are only slightly soluble at a moderate degree of acidity. The microbial activities of the soil are greatly influenced by the soil reaction. Availability of phosphorus is affected by factors related to the soil reaction. The degree to which nitrate and ammonium nitrogen may be assimilated by the plant is also a function of the acidity or basicity of the soil solution.

It is possible to provide normal growing conditions in the absence of soil if the roots are provided with adequate water, oxygen, and plant nutrients in proper balance; if the conditions of light, temperature, and carbon dioxide content of the air are favorable; and if adequate support is furnished for the plant. Results obtained by growing plants in culture solutions amply demonstrate that the soil factors requisite to plant growth are those directly or indirectly related to the needs of plant roots for an adequate supply of water, favorable conditions with respect to oxygen, and sufficient plant nutrients in the proper chemical proportions.

DETERMINATION OF SUITABLE SOIL TYPES

It is brought out in other sections of this Yearbook that a soil type connotes a series of interrelated internal and external characteristics. A careful study of these characteristics gives an excellent picture of the degree to which the six fundamental conditions discussed are favorably expressed. Thus, the detailed description of the soil profile may show by a mottled color or impervious structure of the subsoil that aeration is inherently unfavorable. The texture of the upper layers, in association with the features of surface relief, indicates cultural possibilities. The moisture relationships must be evaluated in terms of the entire soil profile. The fertility of a virgin soil—its content of available plant nutrients—is dependent upon the nature of the soil-forming processes and the length of time they have operated, as well as upon the chemical nature of the parent soil material.

The natural characteristics of a soil type are capable of modification by cultural practices, the effects of lime, crop residues, and destruction of organic matter or depletion of chemical fertility by long-continued cropping and accelerated erosion. Hence, many areas of soil types once favorable for a particular crop are no longer suitable, while in many instances naturally infertile soils have been built up to a much more productive state than is normal for the soil type in question. A careful study of the characteristics of the important soil types which are supporting particularly profitable crops of a given plant in each climatic region, however, affords a basis for the evaluation of the soil requirements of the plant.

In all of this discussion it will be noted that climatic conditions are considered to be favorable. Actually, however, it must be remembered that climate is a most important factor determining plant distribution. On the other hand, because soils are an expression of environment, including the climatic forces, a discussion of existing soil types favorable for specific crop plants necessarily connotes also a favorable climatic regime. Any consideration of climate as something apart and distinct from a geographical soil area results only in a hypothetical and artificial situation.

Broadly speaking, relatively permeable and fertile soils of good water-holding capacity are favorable for the growth of most important crop plants. With suitable climatic environment, some soils seem to possess an especially wide range of crop adaptation. Thus, the Hagerstown silt loam of the Appalachian limestone valleys is capable of growing satisfactory yields of practically every field crop, forage crop, vegetable, or fruit of the North Temperate Zone. On the other hand, optimum conditions for corn are more readily provided on the Carrington loam of the Central States, for early market vegetables on the Norfolk sandy loam of the Coastal Plain, or for fruit on the neighboring Frankstown gravelly silt loam of the Shenandoah section. Yet satisfactory crops of corn are produced in every State east of the High Plains from the Gulf of Mexico to the Canadian border. Within this vast expanse one may find good fields of corn on soils differing widely in important soil characteristics. Despite these apparent contradictions, economic plants differ greatly in the degree to which the various soil conditions previously mentioned must be satisfied.

Space does not permit a detailed treatment here of the soil relationships of the wide range of commercial crops grown in the United States and its possessions. The most outstanding soil requirements of the important crop plants will be discussed, however, together with illustrations of especially favorable soils for each. The crops are grouped and arranged alphabetically for convenient reference.

IMPORTANT CROP PLANTS AND THEIR SOIL REQUIREMENTS

Cereal Crops

Barley

Barley, a cool-weather crop, is rather widely distributed in continental United States. Three major barley regions are recognized—the semiarid or western; the humid spring, or northeastern; and the humid winter, or southeastern. It is

grown most extensively in the spring-wheat belt, although it is very important in parts of the hay and dairy region, in the central Great Plains, and as a winter crop in California. Since good drainage is a primary soil requirement, barley is not as well suited as are oats and wheat to certain heavy clay soils of the humid sections. It is more sensitive to mineral deficiency than the wheat crop and is less tolerant of acidity than most other cereals. As a result, sandy soils generally are very unsatisfactory. On the other hand, barley withstands moderate concentrations of alkali and soluble salts. The fact that barley is damaged easily by hot humid weather prevents its being grown on many soils of the Corn Belt that are otherwise favorable. Barley is generally better adapted to the northern Great Plains and less suited to the Corn Belt than oats.

The chief centers of barley production lie in areas represented by the Barnes, Bearden, and Fargo soils of the eastern Dakotas and western Minnesota; the Carrington, Tama, and Clinton soils of southeastern Minnesota; the Kewaunce and Miami soils of eastern Wisconsin; the Clarion, Carrington, and Miami soils of northeastern Illinois; the Keith, Weld, Bridgeport, and Tripp soils of northwestern Kansas, southwestern Nebraska, and eastern Colorado; and the Yolo and Capay soils of the Sacramento Valley of California.

Buckwheat

Buckwheat is a locally important crop in the northern Appalachian area and in certain portions of the Lakes States. It does best where the climate is moist and cool, but it is very susceptible to frost. Its short growing season of 10 to 12 weeks permits maturity at high altitudes and latitudes, and cool nights appear to be quite essential for seed formation.

Buckwheat will produce a better crop on relatively infertile soil than any other grain, provided other conditions, notably climate, are satisfactory. It is well suited to light well-drained acid sandy loams. In fact, an acid soil is apparently preferable for buckwheat. It does not do well on heavy, poorly drained land, or on sandy soils that are exceedingly droughty and infertile. It may be grown on newly cleared land or drained marshland, which carry too much decaying organic matter for ordinary grain crops.

Because of its adaptability buckwheat is largely used as a catch crop. It does not have a definite place in the rotation except in areas notably lacking in productive soils where the more favored cereals will not grow.

The principal areas for buckwheat are the Allegheny Plateau section of New York, Pennsylvania, Maryland, and West Virginia, and the sandy soils of Michigan, Wisconsin, and Minnesota. The principal soils are the Lordstown and Dekalb of the Allegheny Plateau, and the Plainfield, Coloma, Rubicon, and Roselawn of the Lakes States. Phosphorus is usually the only fertilizing element added in the areas where buckwheat is grown to any extent as a cash crop.

Corn

This is a rapidly growing crop, making its maximum demands upon the soil during the late summer period. Varieties differ widely in growth characteristics, ranging in size from the Tuxpan, which frequently attains a height of 12 feet or more, to types like the Gehu that mature at less than 3 feet. In its normal habitat in North Dakota, Gehu will mature in about 90 days, whereas in southern Texas, Tuxpan probably requires about 150 days.

As to the soil requirements for the corn plant, varieties appear to differ chiefly in moisture requirements. Although the water requirement of corn (pounds of water transpired per pound of dry matter) is comparatively low, the tonnage grown per acre brings about a heavy demand for moisture. It may be stated that in practically all instances corn that is adapted to a given climatic region, regardless of variety, must obtain water from the soil during the period of its most rapid growth at a faster rate than any other field crop of the region. In the northern Great Plains at the border of its climatic region, it is to be noted that corn survives hot, dry weather better than spring wheat and because of thin planting does not deplete the soil of moisture so completely. The corn plant is sensitive also to conditions of deficient soil aeration that may result from either excessive soil water, poor tilth, or impervious character of the subsoil.

Corn is grown rather successfully over a considerable range of soil reaction, at least from a pH of 5 to 8. Yields are usually adversely affected, however, by

degrees of acidity represented by pH values less than 5.5, and below a pH of 5 serious diminution in yield is normally experienced. In the United States, corn is not ecologically adapted to the climatic regions where alkaline soils are common. Under irrigation these soils, however, may produce good yields of corn.

Corn requires an abundance of readily available plant nutrients. Nitrates must be furnished by the soil at a rapid rate during the late summer months. A deficiency in phosphorus is especially reflected in a slow initial growth. Although corn has relatively a good ability to obtain potassium from most soils that are not excessively sandy, in a number of Eastern States the soils must be enriched with available potash. This is done either through manuring or fertilization. Magnesium has been found to be deficient for normal growth on some acid, sandy soils of the Middle and North Atlantic States, particularly in seasons of excessive soil leaching. In the South, corn is usually fertilized heavily with complete fertilizer and top dressings of soluble nitrogen except when it is grown on the better soils of the bottom lands.

Of the zonal, or great soil groups, the Prairie soils [4] are inherently the best suited for corn, since they fulfill its requirements most completely and are developed in the region in which the climate is especially favorable. It is no mere accident that the Corn Belt, although more extensive geographically, centers about the Prairie soils, extending from western Indiana to eastern Nebraska. Here the climate and grass vegetation have been largely responsible for the development of fertile soils of favorable reaction and high in organic matter and exchangeable bases. The benefits of the relatively high content of organic matter, such as tilth, water-holding capacity, and available nutrients, are well known and scarcely need further comment. The dark color of the surface of these soils of the grasslands also promotes to some degree a desirable soil temperature.

Probably the best producing soils of the Corn Belt are the artificially drained, dark soils of the glacial-lake depressions and flood plains. They include the Wabash, Webster, Brookston, and Clyde series. From the point of view of soil classification, these highly productive soils are the azonal and intrazonal associates of the Prairie soils. The Tama, Marshall, Clarion, Carrington, and Waukesha are representative and extensive series of the Prairie soils. The Grundy and Muscatine, known as Planosols because of their claypan development, are important corn-producing soils in southern Iowa and northern Missouri. The generalized soil map at the end of the Yearbook shows the general geographic distribution of the Tama, Marshall, Carrington, Clarion, Webster, and Grundy soils. Recent soil survey reports should be referred to for the distinctions that characterize each series as to profile features, physiographic position, and the nature of the parent soil material.

To the west, in the Chernozem region, the Moody soils of Nebraska and South Dakota deserve mention for the production of corn. Other important soils for corn, though less ideally adapted to the crop, are the silt loams of the following series: Clinton (central Corn Belt), Miami (eastern Corn Belt), Hagerstown (Appalachian limestone valleys), Maury (bluegrass region of Kentucky and Tennessee), and Bladen (southern Coastal Plain).

Three other soils that deserve especial mention for their production of corn and their distinctive role in the local agriculture of certain areas of the South and East are the Huntington, Congaree, and Genesee series. These are the well-drained, relatively brown soils of flood plains which differ primarily from each other in the mineralogical composition of the parent material. The associated soils of the uplands, often hilly, stony, and infertile, are used largely for forage, pasture, hay, and grain. A small acreage of these fertile soils on the bottom lands enables successful farm units to be established in areas that otherwise would be relegated to forest. Corn is frequently grown year after year without any appreciable loss in productivity.

Oats

Although grown throughout continental United States, oats are best suited to a cool moist climate. Soil requirements include fair drainage to avoid lodging and disease. A favorable amount of available nitrogen is essential, but at a lower level than for corn. Excessive nitrates cause serious losses from lodging. Responses to phosphorus and potassium are usually less definite than for either corn or wheat, and oats are apparently able to thrive at a lower level with respect

[4] The soil groups and series and their locations are discussed in Soils of the United States, p. 1019.

to these mineral nutrients, although on the sandy soils of the Carolinas and Georgia, the crop responds well to applications of muriate of potash. In certain areas of the Middle West it has been observed that the gray-speck disease of oats is a physiological condition related to manganese deficiency in soils. Although the chief oat-producing soils are nearly neutral in reaction, the crop is not exacting in its lime needs and does well on eastern soils at as low a pH as 5.2. It is not adapted to distinctly alkaline soils. In the South, oats are sown in the fall.

The principal oat-producing region includes much of the Corn Belt of Illinois, Iowa, and southern Minnesota, and overlaps into the Gray-Brown Podzolic region in Minnesota, Wisconsin, Michigan, Ohio, and New York, to the north and east, and into the Chernozem belt to the west. The two most important centers for oats are the northern Iowa-southern Minnesota and east-central Illinois areas where oats are an important crop following corn in rotation. On the soil map at the back of the Yearbook, both of these areas are shown to have the Clarion-Webster and Carrington-Clyde soil associations. Other important soil series are the Moody and Barnes of the eastern Dakotas and western Minnesota, the Tama and Marshall of Iowa, the Miami, Kewanee, Clinton, and Isabella of Wisconsin and Michigan, and the Ontario and Honeyoe of western New York.

Areas of less importance include the belt extending southward from Iowa across eastern Kansas, Oklahoma, and central Texas, valleys in the intermountain States and the Pacific Northwest, and the Southeastern States. The use of oats as a feed crop or as a nurse crop for clover explains in part their distribution in these regions of diverse climatic and soil conditions. An enumeration of the soils producing oats in these areas will not be attempted.

Rice

The physical conditions controlling rice production are temperature, water supply, and soils. This crop in the United States must be grown on soils that (1) are capable of holding irrigation water over the surface for a considerable period, (2) may be drained promptly and quickly, and (3) provide a solid footing for cultural machinery after the removal of water. Rich, dark-colored alluvial soils with impervious subsoils are generally utilized. Fertilization is rarely required under such conditions, although the use of nitrogen in ammonia or organic form, as well as phosphates, is often of benefit.

The culture of rice in continental United States is confined largely to the clays, clay loams, silty clay loams, and silt loams of the Lake Charles series in Texas, the Lake Charles and Crowley series in Louisiana, and the Crowley series in Arkansas. In California the clays, clay loams, and adobe clays of the Stockton, Landlow, and Sacramento series are used.

Rye

Rye is less exacting in its soil requirements than any of the other important cereals. It grows well over a wide range of conditions with respect to soil moisture, although it is adversely affected by deficient drainage. It is able to withstand considerable degrees of acidity and alkalinity. The crop makes a reasonable growth at low levels of fertility, both with respect to available nitrogen and mineral nutrients. On the other hand, it is able to make a relatively luxuriant growth under especially favorable conditions without damage to grain quality. Losses due to lodging from excessive nitrates are much less than with wheat or oats.

As a result of its tolerance for sandy and other relatively infertile soils, it is generally grown on them or as a catch crop where other crops have failed. It is also used as a winter cover and pasture crop, although in the South it is being replaced by winter legumes. The principal rye areas are the sandy lands in North Dakota, South Dakota, Nebraska, Minnesota, Wisconsin, and Michigan, although in the Great Plains rye finds general favor because of greater certainty as a crop than wheat, use for pasture, and the fact that fall sowing lessens spring labor. Some of the soils that may be mentioned are the Barnes and Bearden sandy and fine sandy loams of North Dakota, South Dakota, and Minnesota, the Thurman and Anselmo soils of Nebraska, the Plainfield and Coloma of Minnesota, Wisconsin, Michigan, and the Boone of Wisconsin.

Sorghums

These crops are grown chiefly in southern Great Plains areas under climatic conditions too dry for corn. Their drought resistance enables them to serve as a substitute feed crop for corn. Like corn, sorghums are especially favored by an abundance of organic matter, good aeration, and a liberal supply of plant nutrients. The sorghums probably withstand moderately saline or alkaline soil conditions to a greater degree than corn.

The sorghum-producing area of the Southwest (Kansas, Oklahoma, Texas) is closely associated with the winter-wheat area, although the two areas cannot be said to be identical. In this area where light-textured and heavy-textured soils often occur in an intimate association, the lighter soils of the farm are frequently used for sorghums and the heavier for wheat. Included in these soils are the Amarillo, Miles, St. Paul, Pratt, Abilene, and Grant. Sorghums are also important in southeastern Kansas, where they are produced on the claypan soils (Parsons, Cherokee) and on the Bates. Sorghums for grain are grown also to some extent in the Salt River and Yuma Valleys in Arizona and the Imperial, San Joaquin, and Sacramento Valleys in California.

Other sorghums that have not been included in this discussion are the sorgos or sweet sorghums, broomcorn, and Sudan grass. A scattered acreage of sorgos extends northeastward from Texas as far north as Wisconsin and as far east as North Carolina and Virginia. Sudan grass is known in nearly every part of the United States. Broomcorn is centralized in Oklahoma and Illinois.

Wheat

Although its water requirement is greater, the wheat crop makes a less rapid drain on soil moisture per unit of area than corn. As previously stated, it is recognized in the northern Great Plains that corn produces a better crop than spring wheat in the more droughty years, probably owing to the lower water requirements for the relatively low tonnage of corn produced per acre on the edge of its climatic region. Wheat is less adversely affected by poor aeration resulting from heavy soils than corn. Winter wheat, however, is especially subject to injury on soils maintaining a high water content during the winter months. A favorable organic content is desirable in order to promote good tilth, but in general, the best dark-colored Corn Belt soils are not so well suited to wheat. A moderate liberation of available nitrogen of the soil is required, but excessive nitrates favor serious damage by lodging during the later stages of growth.

Available phosphorus must be at a fairly high level in order to promote the formation of grain. Potash is rarely deficient in soils otherwise well adapted to wheat, although in the States east of the Mississippi River, potash fertilization is becoming increasingly necessary where manure is not used during the rotation. Lime is probably of less direct benefit to wheat than to corn, although wheat is grown most extensively in areas with neutral to slightly alkaline soils. Wheat withstands a moderate concentration of soluble salts and carbonates, but is not adapted to strongly saline or alkaline conditions.

The Chernozem and Chestnut soils may be said to play a role in wheat production similar to that of the Prairie soils in corn production. Although production is less hazardous in the Chernozem belt where rainfall is heavier and the soils are darker and deeper, wheat is relatively a more important crop in the Chestnut and Reddish Chestnut zones, largely because of its ability to produce a product of excellent quality (high protein content), under the semiarid conditions. In fact, under the economic stimulus of high prices during and immediately after the World War too much wheat was grown on land the alternative use of which was grazing.

This condition serves to illustrate the importance of economic as well as environmental conditions in determining the major centers of production of crops.

The principal soils of the subhumid to semiarid grasslands of the Great Plains and Columbia Plateau that are used for wheat are the loams and silt loams of the smoother upland areas, although the Fargo clay and the Pullman and Richfield silty clay loams are exceptions, both in texture and in their physiographic position. The Chernozem soils include the Barnes, Bearden, and Fargo of the eastern Dakotas and western Minnesota; the Holdrege and Hastings of Nebraska and northern Kansas; the Hays of central Kansas; and the Palouse of Washington and Oregon. The principal Chestnut soils include the Williams and Morton

soils of North Dakota and Montana, the Rosebud of South Dakota and Nebraska, the Keith of Nebraska and Kansas, the Weld of Colorado, and the Walla Walla of Washington and Oregon. The principal soils of the Reddish Chestnuts which are used include the St. Paul, Abilene, Pullman, and Richfield of Oklahoma, Texas, and Kansas.

The Yolo soils of the Sacramento Valley of California, developed on alluvial fans, have been important producers of wheat, although today many areas are used more intensively for fruit production. These soils are usually capable of producing up to their climatic yield limits without fertilization. Under continuous cropping, however, it is difficult to maintain organic matter against erosional losses sufficient for favorable tilth and moisture-holding capacity.

Desirable wheat soils in humid sections are Miami silt loam of the eastern Corn Belt, Wooster silt loam, Ontario and Honeoye silt loams of eastern Ohio and western New York, Hagerstown silt loam of the Appalachian limestone valleys, and Georgeville silty clay loam of the Piedmont Plateau. The productivity of these soils is dependent upon adequate fertilization and good rotational practices.

Citrus Fruits

In the restricted climatic limits within which citrus fruits are grown in continental United States—in Florida, the Rio Grande Valley, and southern California—the soils that have been found most desirable are of light or medium texture. Their drainage conditions are almost perfect, with somewhat excessive underdrainage. Commercial fertilizers are required in liberal amounts. The highest quality of fruit is probably obtained on soils containing a relatively high supply of bases. An excessive basicity, however, tends to produce chlorotic foliage. This is probably associated with the unavailability of those elements required for plant growth in only minute amounts. Zinc (*61*) and iron (*134*) compounds have both been beneficial to citrus fruits on such soils.

Under a more restricted moisture supply, the sandy, porous soils most commonly used for oranges might prove too poor in moisture retentiveness. Water, however, is either supplied by irrigation or provided through an abundant, well-distributed rainfall, as in Florida.

The following soils have been extensively used for citrus fruits: Norfolk fine sand, Norfolk fine sand, hammock phase, Blanton fine sand and Orlando fine sand in Florida; Hidalgo fine sandy loam and Victoria fine sandy loam in the Rio Grande Valley of Texas; Fallbrooke fine sandy loam, Hanford sandy loam, and Placentia gravelly loam in California; and the Mohave gravelly and sandy loams in the Salt River Valley in Arizona.

Cotton

This long-season southern crop is represented by a number of types varying considerably in their soil adaptations. It requires a soil of good moisture-holding capacity, with favorable drainage and aeration. Soils well supplied with organic matter are the most productive, although much of the southeastern area is on seriously humus-deficient soil. The crop is successfully grown at various degrees of acidity, the most favorable range being pH 5.2 to 7. The soils east of the Mississippi lowland are generally so deficient in available nutrients that fertilizers are used very extensively. The available nitrogen in the soil is rarely adequate, and both phosphorus and potassium must also be supplemented from fertilizer sources. The rich, dark-colored Rendzina soils of Texas are much more fertile, and fertilization is not so extensively practiced. The breeding of cotton types especially adapted to areas of more restricted rainfall has added extensive acreages in cotton in northern Texas and western Oklahoma on soils of high mineral fertility and well supplied with available nitrogen.

The boll weevil infestation has brought about a distinct change in the use of land for cotton in the Southeastern States. Formerly, the heavier soils were preferred because of their better productivity. With the advent of the boll weevil, cotton has been pushed onto the less fertile, light-textured soils of the uplands, where it matures earlier and partially escapes the ravages of the boll weevil. The withdrawal of cotton production from parts of the Black Belt of central Alabama is an example.

The following soil types are representative of the various cotton sections: Greenville sandy loam, generally regarded as one of the best cotton soils of the

Coastal Plain; Tifton sandy loam of Georgia; Orangeburg fine sandy loam of the Coastal Plain; Norfolk sandy loam of the Coastal Plain; Cecil sandy loam of the Piedmont Plateau; Sarpy, Sharkey, and Yazoo soils of the Mississippi lowland extending from Kentucky to Louisiana; Miller and Portland soils along the flood plain of the Arkansas and Red Rivers in Arkansas, Louisiana, Texas, and Oklahoma; Houston black clay of Texas; Miles fine sandy loam of northwest Texas; Enterprise very fine sandy loam of Oklahoma; Gila, Pima, Mohave, and Laveen soils of New Mexico and Arizona; Imperial, Holtville, Meloland, Hanford, and Delano soils of California. These soils of the arid Southwest have a wide range in texture, from sandy loam to clay.

Flax

In the United States flax is grown almost entirely for its seed, flaxseed or linseed, although some 3,000 to 5,000 acres of fiber flax are grown annually in the Willamette Valley of Oregon. Seed flax is grown chiefly in the spring wheat area of Minnesota and the eastern Dakotas and in southeastern Kansas. Recently flax has been grown very successfully as a fall-sown crop under irrigation in California. The acreage of flax varies considerably from year to year in spite of favorable prices as compared to spring wheat, its chief competing crop. Flax is well adapted to the cool climate of the North Central States where the principal precipitation occurs during the growing season. Some years ago the crop was grown to some extent farther west in the northern Great Plains, but during the recent drought years its cultivation in that area has been almost entirely discontinued.

Flax is not exacting in its soil requirements, its production depending principally on rainfall and a moderately cool climate. It is tolerant of a comparatively wide range in pH values. The crop is well adapted to the Chernozems of the eastern Dakotas, the Prairie soils of southern Minnesota, and the Planosols of southeastern Kansas. The crop does well also on sandy loam soils if the supply of moisture is adequate. In California, flax is grown very successfully under irrigation on sandy soils of the Imperial Valley, the so-called soft lands. In the North Central States the hazard of wilt has been overcome by the development of wilt-resistant varieties. Flax diseases are not a factor thus far in Kansas and California. Weeds are perhaps the greatest hazard to successful flax production. The control of weeds by means of crop rotation is an important practice in every area where flax is grown.

Grasses

Kentucky Bluegrass

This grass is the dominant species in the best grazing areas east of the Great Plains. Both good drainage and moisture-holding capacity of the soil are essential. The conditions of chemical fertility for best results are rather exacting. Large amounts of nitrogen must be available during the periods of most active growth, particularly in the spring, early summer, and autumn. Kentucky bluegrass is frequently associated with white clover, a nitrogen-fixing plant. Nitrogen fertilization, however, is generally needed, as the usual irregular occurrence of the white clover does not furnish sufficient nitrogen for maximum production of grass under present farm practices. Phosphorus is important, particularly for associated legumes, and soils must be either naturally rich in this element or maintained at a reasonable level of phosphorus availability by farm practices. Although the plant is able to obtain a sufficient amount of potash from most soils that are otherwise favorable, nitrogen and potash are the most effective fertilizers for growth on certain soils, such as the Sassafras silt loam.

The soils must be well supplied with calcium. The most desirable pH range is probably 5.8 to 8.2. Because of the cost of lime applications on an extensive scale, the chief areas of bluegrass grazing are still confined to soils developed from calcareous material.

Representative soils suitable for the crop in important grazing sections are Maury silt loam of Kentucky and Tennessee; Hagerstown, Frederick, and Dunmore silt loams of the Appalachian limestone valleys; Calais loam of Vermont; the Baxter silt loam of the Ozarks; the Clinton silt loam of the upper Mississippi Valley; Fairmount silty clay loam of Kentucky, Ohio, and Indiana; Honeoye and Ontario silt loams of New York. The typical Corn Belt soils are also usually very productive for bluegrass.

Timothy

Timothy, the most commonly used hay crop in the Northeast, is grown extensively on a wide range of soil conditions over most of the area north of the Cotton Belt and east of the Great Plains. It is also grown in the Pacific Northwest and to a very limited extent in the intermountain region, both with and without irrigation. It is rather sensitive to deficient moisture conditions during the early summer period when it is producing its seed-bearing spike. Fairly good drainage is required. Timothy is adapted to a considerable range of soil reactions but is adversely affected by high acidity to about the same degree as corn. Natural moisture conditions in most soils containing carbonate accumulations are rarely adequate, but under irrigation timothy is an important crop, usually in mixtures with clover. Timothy produces good crops on many eastern soils at a relatively low fertility level, although yields are improved by manuring and fertilization. Nitrogen is especially beneficial in the top dressing of timothy hay lands.

The most favorable soils for timothy, in general, are those of the flood plains, such as the Tioga and Chagrin of New York, the Genesee of New York, Ohio, Indiana, and Michigan, the Huntington of the limestone valleys of Pennsylvania, Virginia, and Tennessee, and the Wabash of Iowa and Missouri. These soils, as previously stated, are also most favorable for corn. As a result, hay production is commonly more important on other soils, less suited for the other crops. In the North Central States corn, oats, and hay form the common rotation, so that the principal hay-producing soils such as the Miami, Clarion, and Carrington are also important for corn and oats. In sections farther north where climatic conditions are relatively unfavorable for crops other than the grasses and where topography and stoniness interfere with tillage, hay is grown in a longer rotation, and the soils become important primarily for the production of this crop. The Spencer of Wisconsin, Ontonagon of Michigan, Canfield, Dutchess, Lordstown of New York, and the Worthington, Berkshire, and Blanford soils of New England are examples, although their relative importance varies with the type and kind of associated soils.

Legumes

Alfalfa

This perennial legume is grown extensively in long rotations on dairy farms of the East and Middle West. It is also grown directly for the market, and is being used more and more in relatively short rotations. West of the range of red clover, it is the chief legume hay crop. Its exceptionally deep and extensive root system gives it an especial advantage in certain areas where surface moisture may be deficient, although a moderately moist soil must be provided for its initial stages of seedling growth and best yields are obtained on irrigated soils. It requires excellent underdrainage for its best growth in long rotations. Some of the soils of the eastern Corn Belt, capable of growing good corn or wheat, are thus ill-favored for alfalfa, especially those with impermeable subsoils. Other unsuited soils are those underlain by bedrock at a comparatively shallow depth.

Alfalfa is especially sensitive to soil acidity and rarely grows to advantage at pH levels below 6. It tolerates alkali and salt concentrations better than most other farm crops, although sweetclover excels alfalfa in this respect.

Alfalfa is also quite averse to phosphorus deficiency, and in the eastern half of the area of its occurrence it must be heavily phosphated. Potash is often a limiting factor, especially on the sandier soils, which have a poor reserve of available potash in the subsoil.

Being less limited by deficiencies of soil moisture than most other legumes, alfalfa is especially well distributed over the western half of the United States. As to the relative merits of sweetclover and alfalfa in respect to water requirements over a period of years, comparisons between perennial and biennial plants cannot well be made. If comparison is made of the seedlings in the second year's growth, sweetclover is more drought-resistant than alfalfa. In the West, however, the main centers of alfalfa production are on irrigated lands. The characteristics of practically all soils developed under conditions of low rainfall are both chemically and physically favorable to alfalfa, with the exception of those which are strongly alkaline, salty, or excessively sandy.

Important alfalfa-producing soil series in various sections are the Hagerstown of Pennsylvania-Virginia-Indiana; the Honeoye and Ontario of New York; the

Kewaunee, Miami, and Fox of Wisconsin-Michigan-Indiana-Ohio; the Waukesha, Hall, and Moody of Nebraska; the Summit of Kansas-Missouri; the Bearden of the Red River Valley; the Miller, Yahola, and Reinach of Texas and Oklahoma; the Fort Collins and Prowers of Colorado; the Ralston of the Big Horn Basin, Wyo.; the Gila and Mohave of Arizona; the Hanford and Yolo of California; the Portneuf of Idaho; and the Ritzville of Idaho, Washington, and Oregon. The Davidson clay loam of the Piedmont section is locally very important, although its contribution to national production is small. Other soils locally important have been omitted, and no mention has been made of soils in Utah because the recent date of soil surveys in much of the State has prevented the correlation of the soils there.

Beans (Dry)

Beans to sell in the dry shelled state are grown on a relatively wide variety of soils. The best yields are obtained on the soils of medium and heavy texture that are well supplied with plant nutrients and organic matter. The highest producing fields in Michigan, for example, are on the dark-colored soils in the Saginaw Valley. Beans can be grown on the lighter-colored, sandier soils if properly fertilized and grown in rotation with other leguminous crops, such as the clovers and alfalfa.

The principal bean-producing sections include the Ontario-Honeoye soil area of western New York; the Saginaw Valley and adjoining glaciated upland of southern Michigan, where the Kawkawlin, Brookston, and Miami soils are important (these are included in the Toledo-Vergennes and Miami-Kewaunee areas of the soil map at the end of the Yearbook); the irrigated northeastern Colorado section of the Weld and associated soils; the Portneuf soils of the irrigated Twin Falls section of Idaho; and irrigated valleys in New Mexico, Montana, and California.

Red Clover

In the humid region, red clover is the most commonly used legume in general crop rotations, either seeded alone with grain crops, or in combination with grasses such as timothy. While somewhat deep-rooted in its habit, it requires a soil of good moisture-holding capacity. On the other hand, it is sensitive to poor underdrainage. On heavy soils practically saturated with water during winter months, serious winter-killing is often experienced.

Red clover is moderately exacting in its requirements with respect to soil reaction. Soils more acid than pH 5.6 rarely produce good clover crops. It is fairly tolerant of alkali and saline conditions. Being a legume, when the soil contains the proper strain of *Rhizobium* for nodule production, it is practically independent of available nitrogen from the soil. Soils that are especially deficient in humus, however, rarely provide suitable physical conditions. Readily available phosphorus in the soil is especially important, and phosphorus-deficient soils must be liberally fertilized with phosphatic fertilizers. This crop, which uses a relatively large amount of potash, is capable of utilizing both surface and subsoil potassium to good advantage. As a result, potash fertilization gives direct benefit only on a few especially potash-deficient soils.

This crop is grown extensively on a wide range of soil type, from eastern Nebraska to New England and from Tennessee to northern Minnesota. It is also important in the Pacific Northwest and intermountain States. The chief factors that have restricted its success are heavy, intractable subsoils, excessive soil acidity, and depleted mineral fertility. Representative types especially well suited to clover are Marshall and Carrington silt loams and Clarion loam of the central Corn Belt; Fox and Miami silt loams of Ohio, Indiana, Michigan, and Wisconsin; Brookston silty clay loam (drained) of Michigan, Indiana, and Ohio; Ontario and Honeoye loams of New York; Hagerstown silt loam of Pennsylvania and Virginia; Davidson clay loam of Virginia and North Carolina; Maury silt loam of Tennessee and Kentucky. These soils are characterized by their relatively high content of bases, particularly potassium, and with the exception of the Davidson have been developed from calcareous parent material. The Maury is noted for its high content of available phosphorus. The Willamette and Chehalis soils in the Willamette Valley deserve mention for their production of red clover. The irrigated Portneuf soils of Idaho are used for hay and seed.

Peanuts

Peanuts are one of the important cash crops in southeastern Virginia, northeastern North Carolina, southwestern Georgia, and southeastern Alabama. They are used chiefly in the manufacture of oil, peanut butter, candy, confectionery products, salted peanuts, and for stock feed. Suffolk, Va., is said to be the largest peanut market in the world, while Dothan, Ala., claims to be the center of the section of greatest production.

The soil requirements for this crop differ according to the varieties. The Spanish White has a much wider soil adaptation than the Virginia Bunch, Virginia Runner, and the North Carolina varieties. It does well on both light-textured and heavy-textured soils, but it produces the best yields and the best quality product on the Red soils. It is grown principally in southwestern Georgia and southeastern Alabama on the Orangeburg, Greenville, Tifton, Norfolk, and Ruston soils. The Lenoir and Craven soils of southeastern Virginia are also utilized.

The large peanuts commonly sold in hulls on the open market are of the Virginia and North Carolina varieties. These varieties are confined largely to lighter-textured and well-drained soils. The Norfolk sandy loams, Norfolk sandy loam, deep phase, and to some extent the loamy fine sand produce an excellent quality of these varieties. Dark-colored soils are objectionable as they stain the hull and lower the market price.

Peanuts require light fertilization, that is, from about 200 to 400 pounds of 2-8-6 or 400 pounds of 0-10-6. Good results are obtained also from a light application of lime.

Soybeans

Although this crop is grown in many sections from Missouri and Iowa eastward to the Middle Atlantic States and southward to the Gulf of Mexico, its chief commercial development is in Illinois, Indiana, and neighboring States. Central and eastern North Carolina are relatively important sections also. Soil conditions favorable to corn are normally well suited to soybeans. Growth is limited on humus-deficient heavy clay, and very strongly acid soils, although soybeans are comparatively much more tolerant of acid soils than is red clover. Abundant soil moisture is desirable, although the soybean does withstand drought remarkably well.

The soybean section in Illinois and Indiana is found principally on the Carrington-Clyde, Tama-Marshall, Putnam-Vigo, and Miami-Brookston areas as outlined on the generalized soil map at the back of the Yearbook. In northeastern Missouri, soybeans are grown on the claypan soils such as the Grundy and Putnam. In the Piedmont of North Carolina the Georgeville silty clay loam may be mentioned, while to the east on the Coastal Plain the Bladen, where drained, is used successfully. In Louisiana, soybeans are grown largely on the alluvial and low terrace lands of the Mississippi and Red Rivers.

Orchard Fruits

No one criterion will serve in selecting an orchard site. Several are closely interrelated, notably elevation above surrounding country, topography, soils, and the weather characteristics of the immediate region. In special cases the proximity of large bodies of water is an important factor, as in States bordering the Great Lakes. Occasionally, economic factors encourage the selection of soils of only mediocre orchard quality. It has been well stated (*295*), however, that experience indicates that the soil alone may often cause a 50- to 100-percent difference in yield.

The prime requisites for soils to be suitable for orchards are that they must hold within the root zone sufficient water to carry the trees through periods of drought and yet be sufficiently permeable to permit ready penetration of roots, air, and water. The profile characteristics of the soil in relation to drainage and depth to bedrock are of especial importance. Sweet and Oskamp (*391*) have emphasized the factors associated with drainage, in the orchards of western New York, which included "the degree and extent of mottling in the subsurface and upper subsoil, pronounced mottling and iron concretions often being observed where the movement of water is slowest; the presence of a so-called gray layer or a well-defined change in the horizon revealing a sharp transition from a darker

subsurface to a light gray stratum, where drainage is poor; an impervious layer of clay rather near the surface, retarding the downward movement of water. Depressional or pocketed areas, particularly where the subsoil is clay, are associated with missing, dead, or dying trees."

The limestone valley of Virginia, Maryland, and Pennsylvania is an example of a region in which the root zone of certain soils is limited by rock rather than by a high water table. In western irrigated areas, the most important consideration is to have a soil that is light textured or pervious enough to take up water from irrigation satisfactorily but not so light textured or porous that its water-holding capacity is too low.

In earlier times there was a prevailing idea that land too infertile for farm crops might well be used for an orchard. This notion may have resulted from

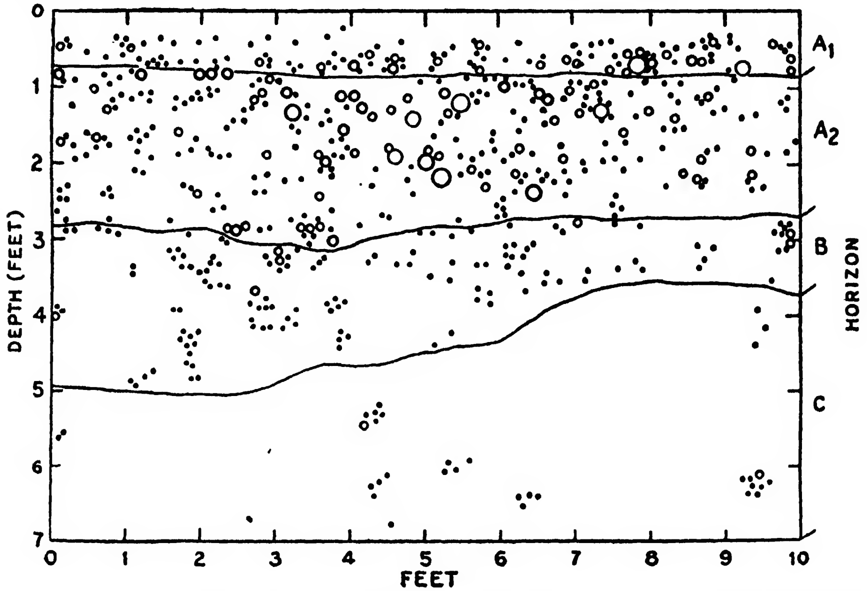

FIGURE 1.—Root distribution on Alton gravelly loam. A_1, brown gravelly sandy loam; A_2, brownish-yellow sandy loam; B, water-worn sandstone and gravel embedded in reddish-brown sand; C, gray sand, loose. Satisfactory rooting in a uniform brown profile. The different sizes of circles represent approximate root diameters as follows: Black dot 0–2 mm, smallest light circle 2–5 mm, next larger heavy circle 5–10 mm, next larger light circle 10–20 mm, and so on, in gradations of 10 mm, the circles being alternately heavy and light.

the observation that trees usually lived and bore fruit on obviously poor soil, while fruit trees on exceedingly fertile soil were subject to winter injury, frequently unreliable in bearing, and more subject to blight and other troubles than those which made a slower growth. The prevailing opinion at present would counsel the avoidance of extremes with respect to available plant nutrients. A moderate degree of fertility is desirable, especially in order to promote the satisfactory growth of cover crops desired to maintain the organic matter of the soil at a favorable level. Most commercial orchardists now practice nitrogenous fertilization, and complete fertilizers are increasingly considered desirable in long-time orchard fertility maintenance.

The deciduous fruits have such a wide tolerance to soil reaction that no definite optimum can be identified. Veatch and Partridge (*442*) state that "the range in reaction in the surface layers, or solum proper, was found to be from a pH of 4.5 to 7.5, but no definite correlation of either good or unsatisfactory growth was established within this range." The effects of soil reaction are to be considered chiefly in relation to the growth of cover or interplanted crops. Liming of the

soils beneath fruit trees has never been an established practice. Very alkaline soils must be avoided, since various types of chlorosis are common under such conditions and the early death of the trees may occur.

From a physical standpoint the ideal texture is a loam. Loamy sand, sandy loam, heavy silt loam or clay surface soils, however, may be suitable for orchards if the other conditions are favorable. In no case should there be bedrock, hardpan, or a waterlogged stratum within the rooting zone.

The requirements and limitations of orchard soils are well illustrated by Oskamp's (*290*) descriptions of a good and a poor orchard soil in western New York, summarized in the following paragraphs.

The Alton gravelly loam contains varying proportions of sand and gravel, as it has been developed over irregularly stratified deposits of these materials. It is

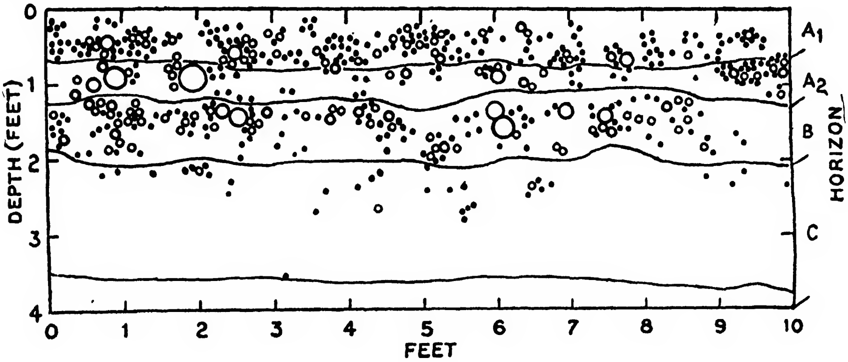

FIGURE 2.—Root distribution on Lockport loam. A_1, reddish-brown loam, firm; A_2, ash-gray sandy loam, compact; B, Indian-red silt loam, very compact; C, Indian-red and brown, very compact and gravelly soil mass, with pockets of clay. The trees on this soil are the most shallow-rooted of those on any soil studied in this area. The different sizes of circles represent approximate root diameters as explained in the legend for figure 1.

open and porous, with excellent internal drainage. The colors of the soil profile are slightly varying shades of brown except at the lower depths, where layers of grayish water-washed sand and gravel may predominate. The average annual yield (3-year average) of Baldwin apples on this soil is 12.3 bushels per tree, as contrasted with an average of 6 bushels on 10 soils studied. The yield of Rhode Island Greening is 8.9 bushels, as compared to an average of 7.4 bushels. The root distribution found in this favorable soil is shown in figure 1.

In contrast, the Lockport loam is an inferior heavy type. A rather large proportion of gravel and slabs of red sandstone occurs in the soil, and particularly in the subsoil, the stoniness increasing with depth to an almost impenetrable mass at 3 or 4 feet. The average yield of Baldwin apples on this soil was 3.6 bushels, as compared with 12.3 bushels for the Alton gravelly loam, and 6.9 bushels as the average for 10 soils studied. Rhode Island Greenings yielded 2.2 bushels as compared with 8.9 bushels on the Alton soil, and 7.4 bushels for the 10 soils. The shallow root system is well illustrated in figure 2.

Orchardists are becoming more and more conscious of the adverse influence of compactness of soils for orchards. Heavy implements and constant cultivation of the land are important agents in compacting a soil and hence in bringing about poor aeration and lack of porosity. One index of the openness of the soil is its percolation rate. A large number of tests must be made at different soil depths, since the soil varies greatly even within small areas. The laboratory method of Bouyoucos (*41*) has been found useful in such studies.

Remedial measures are often attempted to overcome undesirable features of soil used for orchards. Large amounts of organic matter may be worked into the soil in order to improve the physical condition and water-holding capacity. Often this is attempted on soils that are infertile, very acid, or wet, with disappointing or unprofitable results. Wet soils are tiled, shallow soils are plowed

deep, sometimes with special deep-tillage tools to break up a hardpan or impervious subsoil. Dynamite is used at times to loosen a compact substratum where the tree is to stand. Improvements resulting from the above measures sometimes warrant their expense. They rarely overcome the handicaps of a poor soil, however, and cannot compare with results obtained when a deep, well-drained, well-aerated, and moderately fertile soil is selected at the outset.

Apples

The foregoing considerations are especially applicable to the apple crop. There are also special varietal considerations. Thus, the Rhode Island Greening appears better suited to rich, heavy soils than the Baldwin. Most of the apple acreage is found in the eastern and northern parts of the United States where the summers are comparatively cool and the winters are less severe than in the interior of the continent. These include the Hudson River Valley section and the Lake Ontario plain of New York; the limestone valleys of Virginia, West Virginia, Maryland, and Pennsylvania; sections of New England; the western Michigan area; the western Illinois district; and the Ozark region.

Although most of the apple acreage is in the East, the most important individual apple-producing areas from the point of view of intensity of production are the Wenatchee and Yakima Valleys of Washington. Other areas of the West that are irrigated or receive supplementary irrigation are the Hood River Valley in Oregon; the Payette-Weiser area, Idaho; the Grand Junction-Delta-Montrose district, Colo.; and the Sebastopol and Watsonville districts, Calif.

Among the many soils that are used for apples throughout the country, the following are distinctly important: The Dunkirk of the Ontario district; the Dutchess of the Hudson Valley; the Frederick, Frankstown, and Murrill, of the limestone valleys; the Isabella, Miami, and Hillsdale loams of Michigan; the Baxter and Clarksville soils of northwestern Arkansas and southwestern Missouri; the Wind River loam of the Hood River Valley; and the Wenatchee loam of Washington.

Cherries

Cherries require less moisture than apples and are frequently grown on soils of light texture. Deep, dry sands are objectionable, however, except in a few instances where water may easily be supplied in plentiful amounts. The following soils are especially productive in important centers of production: Dunkirk and Alton sandy loams of western New York, Roselawn loamy sand of Michigan, and the Whatcom silt loam of northwestern Washington. Cherries are also produced in the Yakima Valley of Washington on what was broadly mapped as Yakima sandy loam in 1901. The Longrie, Posen, and associated soils should be mentioned for their production of cherries in Door County, Wis., although they were not recognized as such on the older soil map of this important cherry-producing peninsula.

Peaches

This crop is most commonly grown on soils of somewhat lighter texture than is considered most desirable for apples, although the best apple soils are also suitable for peaches, within their climatic limitations. The following are typical of important peach sections: Palmyra and Alton gravelly sandy loams of western New York; Manchester gravelly sandy loam of Connecticut; Norfolk sand of North Carolina; Greenville sandy loam of Georgia; Fox sandy loam of Michigan; Princeton fine sandy loam and silt loam of southwestern Indiana; Memphis (Ava) silt loam of southern Illinois; Tujunga sand, irrigated, and Yolo fine sandy loam of California.

Pears

In general, pears appear better adapted to somewhat heavier soils than other orchard trees. However, adequate depth of soil suitable for root development, with good drainage and aeration, is especially important. Excessive available fertility, particularly with respect to nitrogen, is to be avoided from the standpoint of twig injury.

The following soils have been found desirable in important areas of pear production: Hudson silty clay loam of the Hudson Valley, N. Y.; Darien and Col-

lamer silty clay loams of western New York; Nappanee silt loam of Michigan; Gibson silt loam of southern Indiana and Illinois; Medford gravelly clay loam of Oregon; and Aiken silty clay loam of California.

Plums

The soil requirements for plums appear to be similar to those for pears. In California, where the prune types are most extensively grown, the Yolo silt loam is typical of a highly productive prune soil.

Potatoes

Although primarily a crop of cool and moist climates, potatoes are extensively grown over a wide range of soils, throughout the northern humid sections and in irrigated districts. Loam, fine sandy loam, or silt loam soils having deep mellow subsoils with especially good underdrainage are most desirable. The crop requires moist soil conditions at all times, without any tendency toward poor aeration. A high state of chemical fertility must be either naturally present or artificially provided. The potassium requirements are relatively high. The crop does well over a considerable range of soil reaction. In the Northeast, where scab-sensitive varieties are grown, reactions between pH 4.8 and 5.4 are considered best. Much of the western production, however, is on less acid or slightly alkaline soils.

Soils upon which potatoes are grown successfully in various parts of the country are as follows: Caribou loam of Maine; Enfield very fine sandy loam of Connecticut; Bridgehampton loam of Long Island, N. Y.; Wooster and Bath gravelly silt loams of western New York; Sassafras loam of New Jersey; Bladen fine sandy loam, drained, of Florida; Fox silt loam of Ohio, Indiana, and Michigan; Isabella sandy loam of Michigan; Plainfield sandy loam of Wisconsin and Minnesota; Bearden very fine sandy loam of the Red River Valley of North Dakota and Minnesota; Weld fine sandy loam of Colorado; Havre loam of Montana; Portneuf silt loam of Idaho; Sauvie silt loam of Oregon; peat of the Sacramento-San Joaquin delta, Calif.; and Yakima sandy loam of the Yakima Valley, Wash., as it was broadly mapped in 1901.

Small Fruits

Blackberries, Raspberries, and Dewberries

These crops may be grown on a variety of soils provided the soils are moderately fertile, well drained, easily cultivated, and of good moisture-holding capacity. Conditions of air drainage are important. Air pockets are subject to frost and disease, while exposure to strong winds causes unfavorable drying, both in winter and summer. These crops are generally grown on acid soils without the use of lime. Fertilization is practiced to only a limited degree. It is difficult to point out distinctive soils for the production of blackberries, raspberries, and dewberries, because of their wide distribution in small acreages. In many areas, these crops are grown on soils also selected for orchards, especially for peaches and cherries. Some of the representative soils on which they are grown are the Napanee silt loam of Michigan, the Baxter silt loam of the Ozarks of Missouri and Arkansas, and the Norfolk fine sandy loam of Texas. The Puyallup Valley of Washington probably represents the most intensive small fruit district in the United States. The Everett-Alderwood-Kittsap association of soils occupies this area. Detailed surveys now in progress will furnish more specific information as to soil conditions in this and other small-fruit districts in the West.

Blueberries

Blueberry culture in recent years has rapidly reached importance in a few special areas of the Coastal Plain, as in New Jersey and North Carolina. As a part of the native vegetation, wild blueberries are associated with the leached and acid soils of the Podzols, Brown Podzolic, Gray-Brown Podzolic, and the Red and Yellow Podzolic groups, including both dry and imperfectly drained sandy soils.

It is recommended that land to be planted to blueberries in New Jersey (*29*) consist of shallow muck overlying sand that is underlain with hardpan at 3 to

4 feet. Irrigation is necessary in dry weather if higher lying and less moist land is used. Deep peats are unsatisfactory. Methods of fertilization are being developed. The soil types best suited are Leon fine sand and Leon sand. These are associated members of the Lakewood-Dukes soil area shown on the soil map in the Yearbook.

Cranberries

Cranberry culture like blueberry culture is of particular importance in a few special areas. Massachusetts, the outstanding State for cranberry production, markets more cranberries than the other States combined. The next States in the order of their production are New Jersey, Wisconsin, Washington, and Oregon.

The cranberry grown for commercial production is the large or American cranberry that is found growing wild in the swamps of northern United States from Virginia to the Pacific coast. Various varieties have been selected and developed for commercial production. Other related plants include the small or European cranberry, the southern mountain cranberry, and the highbush cranberry used for ornamental purposes.

The cranberry is like the blueberry in that it requires an acid soil. Conditions of water supply for controlled flooding are very important and the plant is grown in bogs and never on the upland. In Massachusetts, peat and muck bogs are used, to the surface of which sand has been added. In New Jersey, shallow muck overlying sand underlain by hardpan is recommended (*45*) as it is for blueberries, although apparently a much greater depth of muck and peat is tolerated by the cranberry.

The principal sites for cranberry bogs in Massachusetts and New Jersey occur within the Lakewood-Dukes soil associations, as shown on the soil map at the back of the Yearbook. Besides bogs, the St. Johns sand and Leon fine sand are used in New Jersey. The muck and peat lands associated with the Plainfield-Coloma area of central Wisconsin make that the important cranberry-producing section of the State. The bogs of the Olympic-Melbourne and Everett-Alderwood-Kittsap associations account for the cranberry production in the Northwest.

Grapes

The exact explanation of the apparent superiority of certain soils for the production of grapes of especially fine quality for fruit or wine has not yet been discovered. It may well be that local climatic factors associated with the occurrence of these soils are more important than the soil itself.

Most good grape soils are deep, mellow, well-drained sandy loam, loam, or silt loam soils, containing a considerable amount of gravel or shaly rock fragments. Favorable moisture retentiveness must go hand in hand with highly favorable soil aeration. A moderately high level of available chemical fertility must be maintained, especially with respect to phosphorus and potassium. While the soil may be moderately acid to slightly alkaline in reaction, the best soils for grapes are not seriously depleted in basic constituents.

The following soils are typical of the important grape districts: Dutchess gravelly silt loam of the Hudson Valley; Dunkirk gravelly loam of the Lake Erie shore, in New York and Pennsylvania; Chenango loam, gravelly phase, of western New York; Baxter silt loam of the Ozarks; Aiken gravelly clay loam, Pleasanton gravelly sandy loam, Placentia sandy loam, and Hanford sandy loam of California.

Strawberries

Although light loams and sandy loams appear to be especially desirable, strawberries may be grown upon almost any type of soil, provided it is retentive of moisture, fairly fertile, and well drained. A moderate level of fertility is desirable. Fertilization is most intensively practiced in the Southeastern States. Phosphorus appears to be the element most needed in the soils of the Mississippi Valley region and nitrogen in the soils of the Coastal Plain. The reaction of the soil is not apparently a limiting factor in strawberry production, as the plant does reasonably well on soils very strongly acid to alkaline. Experiments have shown that best growth is obtained on soils with a range of pH 5.0 to 7.0 provided the organic content is relatively high, but with lower organic content the range for best growth is much less—5.7 to 6.5 or less.

The following soils are typical of areas well suited to the crop in commercial districts: Elkton sandy loam, artificially drained, of Delaware; Keyport sandy loam, artificially drained, of Virginia; Denham and Olivier silt loam of Louisiana; Baxter silt loam, Clarksville shale loam, and Hanceville shale loam of western Tennessee and the Ozarks area of Missouri and Arkansas.

Sugar Crops

The sugar crops consist of sugarcane and sugar beets. Of the raw sugar produced in the United States (continental United States, Hawaii, and Puerto Rico), approximately 65 percent is cane sugar and 35 percent beet sugar. In 1936, about 40 percent of the raw cane sugar was grown in Puerto Rico and about 45 percent in Hawaii. All of the beet sugar and the remainder of the cane sugar was grown in continental United States. The total production amounted to about 3,726,000 short tons of raw sugar.

Sugarcane

This crop requires a relatively high temperature and considerable sunshine together with liberal amounts of available soil moisture during the growing season. For best yields, other soil requirements are rapid availability of soil nitrogen, abundant supply of available mineral nutrients, and a relatively deep and friable subsoil for root development. Sugarcane is tolerant of moderately acid to moderately alkaline conditions. In general, those soils developed under relatively low rainfall, when properly irrigated, are more productive in terms of sugar per acre than the soils of the humid areas.

The chief development of sugarcane for sugar production in continental United States has been on the fertile alluvial soils of the lower Mississippi Valley in Louisiana, although Florida also contributes. The Iberia, Lintonia, and Olivier are the principal soils. The Yazoo soils shown on the older soil maps probably would be correlated differently today. Climatically, the region is handicapped by the danger of frost. In addition to the more localized production of sugar, sugarcane is generally grown in small patches throughout the Gulf Coastal Plain for local sirup production.

A comparison of yields for 1936 as reported in Agricultural Statistics for 1937 (*431*) shows the average acre yields of cane in Hawaii, Puerto Rico, Louisiana, and Florida to be 70.1, 25.3, 17.6, and 35.3 short tons, respectively. In the same order, the pounds of sugar made per ton of sugarcane are given as 222, 244, 156, and 180.

Sugar Beets

The production of the crop is highly localized by economic, climatic, and to less degree by soil factors. The growing of sugar beets has developed chiefly within the zone marked off by the isotherms of summer temperature of 68° and 72° F. mean temperature. Sugar beets are influenced strongly by temperature conditions of the growing season. Under conditions of warmer temperature than those of the zone mentioned, sucrose accumulation in the roots may be depressed. Under cooler conditions, the growing season becomes too short.

Soil requirements include a well-drained, deep, and permeable seedbed of good moisture-holding capacity. The fertility level including the lime content should be comparatively high. Attention to these requirements must be given to sugar beets grown under irrigation as well as to those grown without.

Although many districts of northern United States have suitable conditions of temperature, other factors such as type of agriculture, economic conditions, soil conditions, and hazards of disease have limited the production of sugar beets largely to the irrigated sections of the West, the Lakes States, and the Middle West. Protective trade measures have enabled these sections to compete with the cane-sugar production of tropical areas.

The principal centers of sugar-beet production in the humid region are the Saginaw Valley of Michigan, where the Brookston and Kawkawlin soils are utilized; the lake plain in northwestern Ohio, where the Brookston, Pandora, Clyde, and Toledo soils are used; the area in northern Iowa and southern Minnesota of the Webster and Clarion soils; and the Red River Valley in Minnesota and North Dakota where the Fargo and Bearden are the dominant soils.

Important irrigated sugar-beet areas and accompanying soil series include the Scotts Bluff area of Nebraska of Tripp soils; the northeast portion of Colorado of Weld soils; the Arkansas Valley of Colorado and western Kansas of Prowers soils; the Yellowstone Valley districts of Montana and North Dakota of Havre soils; the irrigated sections of southern Idaho of Portneuf soils; the irrigated valleys of Utah, where the soils have not as yet been finally correlated as to series name; and the valleys of California of the Yolo and Sacramento soils.

Sweetpotatoes

The sweetpotato is rather lenient in its soil requirements provided the climatic conditions are satisfactory. These include a growing season of about 4 months with warm days and nights, considerable rainfall early in the season, and plenty of sunshine. Well-drained soils are a prerequisite, with sandy loams the most desirable texture.

The commercial sweetpotato crop is largely centered in the Cotton Belt, northwestern Tennessee, eastern Virginia, Maryland, Delaware, and southern New Jersey. The principal soils are the sandy loams of the Norfolk and Sassafras series. This crop largely replaces the potato throughout the South for home consumption.

Tobacco

The soil requirements of tobacco are somewhat unique, in that in addition to the needs for normal growth, there are certain rather special correlations between soil type and characteristics of quality in respect to each of the various types of tobacco.

In general, tobacco is a crop making very rapid growth during a short season. It requires large amounts of available soil moisture within reach of its comparatively shallow root system, but, at the same time, it is relatively sensitive to poorly drained conditions. Carefully adjusted, though relatively large amounts of readily available nitrogen must be supplied. Bright-leaf tobacco may be somewhat of an exception as to its need for large amounts. The phosphorus needs of the plant are not great, although soils with low levels of available phosphorus permit little growth until corrected by phosphatic fertilizers. Potash is utilized by the tobacco plant in especially large amounts, and the crop has little or no ability to obtain potassium from the "nonexchangeable" potassium of soil minerals. Hence, liberal potash fertilization is ordinarily practiced, except in rotations on land receiving a supply of available potash from large amounts of animal manures. The relative proportions of basic constituents (calcium, magnesium, and potassium) capable of ready assimilation by the plant are important in determining the burning qualities and ash characteristics, especially in cigar types. Chlorides in the soil solution are undesirable because of the objectionable burning effect. In Puerto Rico, there is apparently sufficient sodium chloride brought in as a fine spray by the northeast trade winds for the atmosphere to have a deleterious effect upon the quality of tobacco for a distance of approximately 4 miles from the coast.

Tobacco is capable of normal growth over a wide range of soil acidity. Excessive acidity, however, at pH levels below 5.0, is often harmful to quality or yield, as it results in low supplies of calcium and magnesium, low phosphorus availability, and excessive solubility of manganese and aluminum. As the soil reaction approaches the alkaline range, the black root rot disease is favored, especially in areas like the Connecticut Valley where the crop is grown year after year on the same fields.

The special soil adaptations of various tobacco types have been the subject of considerable investigation. The variation in soil requirements is well illustrated by the representative soil types in the important producing centers for the leading tobacco types, as follows: Cigar wrapper—Merrimac sandy loam, deep phase, of Connecticut and Massachusetts; shade-grown cigar wrapper—Greenville and Magnolia soils of Florida and Georgia; cigar binder and filler—Hagerstown silt loam of Pennsylvania, Russell silt loam of Ohio, and Clinton silt loam of Wisconsin; Burley tobacco—Maury silt loam of Kentucky and Clarksville silt loam of Tennessee and Missouri; flue-cured bright tobacco—Durham, Appling, and Cecil sandy loams of the Piedmont of North Carolina, Norfolk fine sandy loam of the Coastal Plain of North Carolina and South Carolina; fire-cured tobacco—Cecil clay of Virginia and Memphis silt loam of Tennessee and Kentucky; Maryland section—Sassafras fine sandy loam of Maryland.

It is interesting to note that the high-quality cigarette tobacco, the flue-cured bright tobacco, is grown on the light-colored and light-textured soils of the Piedmont and Coastal Plain, which are low in organic matter and in nutrients. The significant thing about these soils is their physical condition, which permits them to serve as a medium to which proper amounts of nutrients may be added. In other words, they are responsive to management because of inherent physical characteristics, and their productivity is a result of the cooperation of management practices with soil characteristics.

Vegetable Crops

Vegetables are most extensively grown on deep, well-drained, friable and permeable soils that may range in texture from fine sands to clay loams. Peat and muck are also important for certain vegetable crops. In general, a high level of readily available chemical fertility and a good supply of actively decomposing organic matter are essential. The high money value of vegetables permits artificial adjustment by the wide use of commercial fertilizers and stable and green manures. Most sandy soils that are best adapted, both physically and climatically, to vegetables are low in a natural supply of nutrients. Special attention is now being given to the adjustment of minor-element deficiencies that are most likely to be encountered on such soils when intensively cropped and heavily fertilized with the purer grades of chemical fertilizer salts. This is not only because of the direct influence of these minor elements on plant growth, but also because of their importance from the standpoint of human nutrition.

Soil-reaction requirements of vegetable crops vary considerably. The majority of vegetables are intolerant of strong degrees of acidity or alkalinity, and liming is a common practice on the vegetable areas of the East and South. Liming on light, poorly buffered soils must be carefully adjusted, however, to meet the needs of the individual crops.

The principal area for commercial vegetable production extends from New York to Norfolk, Va. A second important area in western New York extends westward along Lake Erie to Toledo and Detroit. The area about southern Lake Michigan is important and extends southward into Indiana and Illinois and northward into Wisconsin and Michigan. Other important areas have been developed in Minnesota, Iowa, Missouri, Arkansas, and Texas. Winter vegetables are important in a belt extending across Florida, Georgia, South Carolina, Alabama, Mississippi, and Louisiana to Texas and reaching to Arizona and California. The important sections in California are the Sacramento-Stockton, Los Angeles, and Imperial Valley districts.

The greatest acreages of vegetables grown for home use are found primarily in regions of small farms or subsistence farming. The more important areas include southeastern Pennsylvania, the upper Ohio Valley, the mountainous districts of eastern Kentucky and Tennessee and of northern Alabama, the upper Piedmont region of the Carolinas and Georgia, northern Mississippi, eastern Oklahoma, the Lake Michigan shore of Wisconsin, southeastern Michigan, and central New York. The size of the average farm garden is smallest in the Great Plains.

An important technical development that may well mean an expansion in the acreage of vegetable crops is the frozen-pack method or the preservation of green vegetables by freezing, which so far has been developed principally in the Pacific Northwest.

For convenience the vegetables will be discussed by groups of related plants. No attempt will be made to give in all instances the names of soil series or types upon which the production of the individual groups of vegetables occurs. Certain vegetables would require a relatively long list of limited types while in other instances the information itself as to soil types is limited. The distribution of vegetable production, of course, has been greatly influenced by the location of population centers.

Asparagus

Asparagus does best in locations where the winters are sufficiently cold to freeze the ground to at least a few inches in depth. South-central Georgia is about the southern limit of satisfactory cultivation. A well-drained, very fertile, and deeply porous soil is necessary, as asparagus is a very heavy and deep feeder. There is little possibility of having the soil too rich, especially through

the use of manure. Annual applications of both manure and complete fertilizer at the end of the cutting season are recommended. The outstanding area for the production of asparagus is the delta district of the Sacramento-San Joaquin Valley, where peat and muck are utilized. A second commercial district is in New Jersey, Delaware, and Maryland.

Cruciferae

This group of vegetables includes such plants as cabbage, cauliflower, broccoli, brussels sprouts, kale, collards, and kohlrabi. These plants are noteworthy for their hardiness to cold and for their adaptation to culture in most parts of the country.

The more important soil requirements of cabbage are adequate supplies of moisture and plant nutrients. It is a relatively gross feeder of most of the nutrients and makes rapid growth under favorable conditions. Cabbage usually gives a moderate response to liming. The quality is closely associated with quick growth. Manure and complete commercial fertilizer both should be used liberally, and if fusarium wilt is present in the soil resistant varieties should be selected:

Other members of this group differ in hardiness. For example, collards withstand summer heat the best, while the cauliflower is very sensitive to warm weather, and brussels sprouts are somewhat more hardy to cold than cabbage.

The principal district for late cabbage is in western New York on the Toledo-Vergennes and Ontario-Honeoye-Pittsfield soil associations, as shown on the map at the end of the Yearbook. The Sassafras and Hempstead soils of Long Island are important producers also. Other producing areas illustrate the tolerance of cabbage for different geographical regions. These areas include parts of New Jersey, southeastern Virginia near Norfolk, southwestern Virginia, the lake plain of northern Ohio, the western shore section of Lake Michigan between Chicago and Milwaukee, the district about Green Bay, Wis., and a part of the irrigated section of northeastern Colorado. Early cabbages are an important vegetable crop in Florida, southern Texas, Louisiana, Mississippi, South Carolina, and California.

Cucurbits

This family includes cucumbers, muskmelons, watermelons, pumpkins, and squash.

The cucumber is distinctly a warm-weather crop. It may be grown during the warmer months over much of the country, but is adapted for winter growing in only a very few of the more southerly locations. Again, extreme temperatures of midsummer in certain areas limit it to spring and autumn culture.

The cucumber requires primarily a soil of good physical condition to which the necessary nutrients may be added. A well-drained fine sandy loam is generally most suitable. Fertilization and prevention of insect damage are of prime significance in management.

Although cucumbers are produced quite generally throughout the country, the pickling industry centers in Michigan, Wisconsin, Indiana, Ohio, and New York, while the cucumbers for market (early and fall) are grown largely in the Southeastern and Southern States, with Florida, Texas, South Carolina, and North Carolina having leading acreages. Maryland and New Jersey should also be noted.

The Sassafras-Collington and Norfolk-Ruston soil associations of the Coastal Plain are the outstanding soil areas for cucumbers grown for the market. It is difficult to point out any particular soils for the pickling area aside from the Miami-Kewaunee soil association of Wisconsin and Michigan.

The climatic and soil requirements of muskmelons are about the same as for cucumbers, although in humid sections they seem to develop more perfectly on light-textured soils, whereas cucumbers appear able to do well on moderately heavy soils.

Although muskmelons are grown in nearly every State, the principal centers of commercial production are in irrigated sections of California, Arizona, New Mexico, Colorado, and Texas, and in Arkansas, Michigan, Indiana, Maryland, Delaware, New Jersey, and Georgia.

The pumpkin is one of the few vegetables that thrives under partial shade and for this reason can be grown with corn.

Squash is one of the easiest truck crops to grow and is found in practically all parts of the United States where there is sufficient moisture, although soils relatively high in organic matter are recommended.

Watermelons are rather restricted for their best commercial development to sands and sandy loams in areas with a sufficiently warm and long growing season and in which liberal supplies of nutrients are available. Georgia is the outstanding State for watermelon production, followed by Texas, Florida, South Carolina, and California. The other Gulf Coast States are important, as well as local centers in Missouri, Indiana, and other States.

Onions

Members of this group are the onion, chive, garlic, leek, and shallot. These plants generally thrive under a wide variety of climatic and soil conditions, provided an abundance of moisture and fertility is maintained, together with good physical conditions. Nitrogen, phosphorus, and potash are required in relatively large amounts. The wide adaptability of onions is illustrated by their production in the Connecticut Valley of Massachusetts, in the Red River Valley of Minnesota, in southern Texas, and in western Colorado. Other areas of importance are New York, northern Indiana, and the Sacramento-San Joaquin Valley of California. Some of these soils are mucks, while others include sandy loams and heavy dark calcareous soils, such as the Victoria soils of Texas.

Peas and Beans

Peas are distinctly a crop of cool regions. In the South they are grown during all seasons except summer. Farther north they are a spring and autumn crop. Only in the extreme North and at high altitudes are they grown during the summer. Even there, best yields occur in the spring rather than in the fall or summer.

Well-drained soils are essential, and at the same time they must have a suitable texture and structure to permit a relatively large amount of moisture to be readily available to the plant. Soil reactions should fall between slightly acid and slightly alkaline for best results. Fertility should be maintained at a moderately high level.

Peas are widely grown for the market. Early peas are grown principally in Florida, Texas, and California. Second-early peas are produced primarily in California, South Carolina, Mississippi, and Louisiana. Sections for later peas are located in Colorado, New York, California, Washington, Idaho, New Jersey, North Carolina, and Virginia. The leading States for the canning of peas are Wisconsin, New York, Minnesota, Maryland, Washington, and Michigan.

The general conditions for garden and green beans (snap and lima) are not greatly different from those for the pea, except that beans are less hardy to cold and are evidently somewhat more tolerant of a wider range in soil reaction. One prime prerequisite is to have a soil of suitable physical condition so that there will be no interference with germination and the emergence of the young seedlings.

Root Vegetables

This group includes the turnip, rutabaga, radish, beet, carrot, parsnip, salsify, and taro. These are biennials and store starches and sugars in their roots the first year. They are generally widely adapted climatically and tolerate a wide range of soil conditions. As a result they constitute the most common of the garden vegetables. In general, soils that are well drained, of good physical condition, fertile, and not strongly acid are suitable.

Beets are sensitive to acid conditions. For best results, a well-drained soil of good physical condition, slightly acid to neutral in reaction, and well supplied with available nutrients is recommended.

Carrots are relatively hardy and grow on almost any soil that is moist, fertile, and loose. The best color is obtained on the lighter soils. Sandy loams and mucks are recommended. About the same considerations apply to parsnips, although precautions should be taken against too long a growing season, as they are liable to become oversized, tough, and fibrous.

Radishes are hardy, but they do not withstand heat. The soil should be fertile, moist, and permeable to provide rapid growth. Radishes that grow slowly have an undesirable flavor.

Turnips and rutabagas are essentially cool-weather vegetables. Of the two, turnips can be grown farthest south.

Taro, an important root crop of warm countries, is grown only in a few counties of the South. It is relatively important as a food crop in Puerto Rico and Hawaii and is grown principally on imperfectly and poorly drained soils.

Salad Crops

This group includes lettuce, celery, endive, chicory, cress, and parsley, of which lettuce and celery are the most important.

Lettuce and celery are cool-weather crops and adapted to winter culture in the milder sections. In much of the North they are spring and fall crops, as the summers are too hot. These crops do not tolerate acid soils and they feed heavily on nitrogen. Phosphorus and potash in generous amounts are also essential, as well as conditions of good drainage and moisture supply. Where these requirements are met, production occurs on soils ranging from sand to clay loams and peats. The depth of the permeable soil is particularly important for celery, and this crop seems to be better adapted to the sandier soils than lettuce.

A rapid increase has occurred during the past 10 years in celery and lettuce production. Most of the commercial lettuce crop in winter is grown in California. Other sections contributing are Arizona, Florida, and the Carolinas. The commercial production of lettuce in summer is chiefly in Colorado, Idaho, Washington, New York, New Jersey, and Massachusetts.

Almost all of the celery grown comes from California, Florida, Michigan, New York, New Jersey, and Oregon. In much of the Northeast the principal soils for both celery and lettuce are found on the well-decomposed muck beds that have been artificially drained and to which heavy applications of fertilizer have been made.

Solanaceae (Tomatoes, Peppers, Eggplants)

The tomato is a warm-season plant and requires a relatively long growing season. High humidity and high temperatures together favor foliage diseases, while hot drying winds and low soil-moisture content may result in the dropping of the blossoms. The plant is suited to a wide range of soils ranging from clay to sand in texture. It is comparatively tolerant to acid conditions. It is a relatively heavy feeder and is sensitive to an unbalanced nutrient condition. The setting of fruit is relatively sensitive to the ratio of the nitrogen to the phosphorus supply. For early ripening a warm fertile sandy loam is recommended, while if earliness is not so important, a clay loam may be very desirable, depending, of course, in part on the other associated soil characteristics.

Tomatoes are widespread in their distribution except where the growing season is short, as in the spring wheat belt and the cut-over sections of the Lakes States. The most important district is in eastern Maryland, Delaware, and southern New Jersey on the Sassafras soils. Other important districts occur in Florida, California, Texas, the Ozarks, Indiana, Virginia, Mississippi, and western New York. As tomatoes are produced on a variety of soils, it does not seem advisable to list the soils upon which they are grown. For example, in Florida they are grown on well-drained sandy land, on marl, and on muck, while in the lower Rio Grande Valley, where they are more widely grown than any other vegetable, the soils are principally sandy loams and clay loams of the Brennan, Victoria, Hidalgo, Laredo, and Rio Grande series.

Peppers are much like tomatoes in their requirements, but are more exacting, particularly in regard to temperature conditions. Southern California, Florida, and Texas are regions of principal production.

The eggplant is still more sensitive to the conditions under which it is grown, particularly in relation to temperature and the balance of nutrients.

Spinach

Spinach is a member of the group of garden plants known as greens, although such a classification is largely one of convenience. Other plants of this group are chard and kale. The general requirements of soil and climate are rather similar to those for lettuce and celery, as the plant does not tolerate acid soils, is a heavy feeder on nitrogen and other nutrients, is relatively hardy, and does best on soils of high organic-matter content. The important producing areas are the Norfolk district of Virginia and the winter garden district of Texas.

ANIMALS have certain definite chemical needs that are supplied by the plants on which they feed. If the plant does not contain enough of a given element because of a deficiency in the soil, the animal will not be properly nourished. This has been proved in the case of some phosphorus-deficient areas where livestock develop marked symptoms of disease. It emphasizes the importance of studying the ways in which plant composition is affected by soil composition and other factors. Some of the findings, so far as potassium, calcium, magnesium, and phosphorus are concerned, are summarized in this article.

Some Relationships of Soil to Plant and Animal Nutrition—The Major Elements

By C. A. Browne [1]

IT IS to the primeval lithosphere, or rocky surface of the globe, that plants, animals, and man owe the ultimate origin of the dozen or more mineral elements that are necessary for their existence. Yet a comparison of the relationships between the mineral elements of the lithosphere and those in food plants and the body of man shows a great disparity. This is indicated in table 1, which has been calculated from the averages of various compilations. While the averages given in this table would be changed somewhat by the incorporation of other analyses of the mineral matter of rocks, soils, plants, and human beings, the figures given are sufficiently accurate to illustrate the general trend of elementary transmigrations.

The plant is the great intermediary by which certain elements of the rocks, after their conversion into soil, are assimilated and made available for the vital processes of animals and man. The simple inorganic constituents of the atmosphere and soil are selected and built up by the plant into protein, sugar, starch, fat, organic salts, and other substances of marvelous complexity. The substances thus synthesized by the plant are subsequently elaborated, with additional selections and removals of elementary components, by the vital processes of the animal body into flesh, blood, bones, and other structural materials. To investigate the progressive steps of these transformations of matter by plant and animal life and to make them conform so far as possible to man's special requirements are the chief aims of agricultural science.

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Table 1.—*Approximate percentages of elements (excluding oxygen) in the mineral matter of rocks, soils, food plants, and man*

Element	Igneous and sedimentary rocks [1]	Soils [2]	Food plants [3]	Human body [4]	Element	Igneous and sedimentary rocks [1]	Soils [2]	Food plants [3]	Human body [4]
	Pct.	*Pct.*	*Pct.*	*Pct.*		*Pct.*	*Pct.*	*Pct.*	*Pct.*
Silicon	51.96	71.63	2.05	------	Sulphur	.10	.10	3.03	13.14
Aluminum	15.14	713.74	([5])	------	Barium	.09	.17	([5])	------
Iron	9.48	6.86	1.58	0.13	Chlorine	.08	.07	3.50	4.84
Calcium	6.85	1.02	8.44	42.24	Chromium	.07	.01	([5])	------
Potassium	4.84	3.02	52.85	8.34	Fluorine	.05	.06	([5])	.06
Sodium	5.16	1.08	5.56	6.03	Undetermined (zinc, copper, iodine, cobalt, boron, etc.)	.71	.26	.16	.05
Magnesium	3.90	.68	6.06	1.32					
Titanium	1.16	1.06	([5])	------					
Phosphorus	.25	.12	16.77	23.85					
Manganese	.17	.12	([5])	([5])	Total	100.00	100.00	100.00	100.00

[1] Compilation of many analyses by Clarke and Washington (*66*).[2]
[2] 26 analyses of various soils by Robinson (*313*).
[3] 20 analyses of common food plants, Wolff's Aschenanalysen (*471*).
[4] Average of 2 compilations, by Sherman (*356*) and Bertrand (*33, p. 53*).
[5] Trace.

A comparison of the average elementary composition of the mineral matter of soils and of food plants, as given in table 1, shows several marked differences. Plants possess a very evident faculty of assimilating certain elements, as calcium, potassium, magnesium, phosphorus, and sulphur, in much greater quantities than their abundance in the soil might lead us to suppose, and of more or less effectively rejecting other elements such as aluminum, the second most abundant mineral constituent of soils. If the comparison be extended further to the constituents of the human body, it will be noted (table 1) that the animal organism has selective faculties of further segregating the mineral elements that have been assimilated from the soil by food plants. Thus the ratios of calcium in the mineral elements of soils, plants, and man, in the examples cited, are approximately 1:8:40, those of phosphorus 1:140:200 and those of sulphur 1:30:130, respectively. Attention is again called to the fact that these ratios are not absolute but only indicative of trends. It is significant that silicon and aluminum, the two most abundant mineral elements of the earth's crust, are found only in traces in the bodies of men and animals.

Of the mineral elements whose percentages are listed in column 4 of table 1, only six (iron, calcium, potassium, magnesium, phosphorus, and sulphur) are commonly regarded as essential to plant life. These six mineral elements are also essential to the life of men and animals, who require also for their physiological processes the additional elements sodium and chlorine, which they obtain chiefly in the form of common salt.

In addition to the 15 mineral elements listed in table 1, there are over 30 others which have been found in soil in minute traces; many of these so-called "trace" elements have been detected also in the mineral matter of plants and animals. In recent years it has been found that of these trace elements manganese, zinc, copper, and boron

[2] *Italic* numbers in parentheses refer to Literature Cited, p. 1181.

are essential for the proper development of certain forms of plant life. Similarly, in the case of animals and man, traces of iodine are necessary for normal development, although this element does not appear to be necessary for plants. The relationship of the important minor or trace elements of soils to plant and animal nutrition is discussed in other articles of the Yearbook. The present contribution deals principally with some of the relationships of soils, as affected by climate and other environmental factors, to plant composition and animal nutrition in the case of the four major necessary mineral elements—potassium, calcium, magnesium, and phosphorus.

MINERAL INGREDIENTS OF SOIL SOLUTIONS

The solid matter of the soil solution, from which the plant derives its nutritive mineral elements, consists principally of a complex mixture of the carbonates, sulphates, nitrates, chlorides, and various organic salts of calcium, magnesium, sodium, and potassium. The quantity of its dissolved solids varies inversely with the moisture content of the soil. Thus Ross and White of the Bureau of Chemistry and Soils found from 560 to 570 parts per million of total solids in the solution from a Norfolk sandy loam of 4.58 percent water (air dry) and from 70 to 80 parts per million of total solids in the solution from a Cecil clay loam of 20.40 percent water (air dry).

The chemical composition of soil solutions varies greatly according to the character of the soil, climatic conditions, fertilization, methods of culture, and other environmental influences. While actual analyses of soil solutions from different regions are few, the differences in composition are partially indicated by the composition of the river water of different areas. This is shown in table 2, in which are compared an analysis of the water of the James River, which drains a region of high rainfall, and an analysis of the water of the Pecos River in New Mexico, which drains an arid region of low rainfall (*65*).

Table 2.—*Composition of the mineral matter of rivers from regions of high and low rainfall*

Ingredient	Water of James River (high rainfall)	Water of Pecos River (low rainfall)	Ingredient	Water of James River (high rainfall)	Water of Pecos River (low rainfall)
	Percent	*Percent*		*Percent*	*Percent*
Carbonic acid	42.52	1.54	Silica	14.74	.33
Sulphuric acid	5.26	43.73	Alumina	.58	
Nitric acid	3.32		Iron oxide	.96	
Phosphoric acid	(1)		Manganese oxide	.08	
Chlorine	1.51	22.56			
Calcium	18.49	13.43	Total	100.00	100.00
Magnesium	5.44	3.62			
Sodium	3.52	14.02	Total solids:		
Potassium	3.58	.77	Parts per million	69	2,834
			Percent	.0069	.2834

[1] Trace.

The James River Basin, which receives abundant rains and is well covered with vegetation, yields waters of low solids that are rich in carbonates; the arid Pecos River Basin yields waters of very high

solids that are low in carbonates but rich in sulphates and chlorides. These same relations would in general pertain to the solids of the soil solutions in the two areas.

The effects of continuous cropping and of fallowing upon the composition of the soil solution have been studied especially by Burd and Martin (*55*) of the California Agricultural Experiment Station, who divided samples of each of seven well-mixed soils into three portions. On one portion of each barley was grown for 8 years; a second portion was cropped the first year, but kept fallow the remaining 7 years; a third portion (original unplanted soil) was kept in a closed bin during the 8-year period. Soil solutions, obtained by water displacement, from each of these portions of the seven soils were analyzed. The average analyses (*55, p. 154*) are given in table 3.

Table 3.—*Average composition of soil solutions from cropped, fallowed, and air-dry stored soils after 8 years*

Ingredient	Displaced solution from— Cropped soil	Fallowed soil	Stored soil	Ingredient	Displaced solution from— Cropped soil	Fallowed soil	Stored soil
	P. p. m.	*P. p. m.*	*P. p. m.*		*P. p. m.*	*P. p. m.*	*P. p. m.*
Carbonic acid	85	53	73	Sodium	42	64	116
Sulphuric acid	472	394	238	Potassium	27	63	75
Nitric acid	181	1,560	1,043	Silica			48
Phosphoric acid	1.8	1.7	5.3				
Chlorine		43	263	Total solids	1,097.8	2,871.7	2,349.3
Calcium	203	559	381				
Magnesium	86	134	107	Percent	.11	.29	.23

The solution from the fallowed soil, as compared with that from the original stored soil, shows an increase in sulphuric acid, nitric acid, calcium, magnesium, and total solids, but a decrease in carbonic acid, phosphoric acid, chlorine, sodium, and potassium. The solution from the cropped soil, on the other hand, shows a great decrease in all constituents except carbonic and sulphuric acids. These decreases (involving a dimunution of 1,251.5 parts per million in total solids) give a good indication of the great losses in mineral nutrients sustained by soils as a result of cropping and leaching. The quantity of mineral matter dissolved each year from the soils of the drainage basins of four American rivers has been estimated by Clarke (*65, p. 89*) to average 79.6 tons annually per square mile.

MINERAL INGREDIENTS OF PLANT JUICES AND TISSUES

The mineral matter imbibed by the plant from soil solutions of low solid content (varying from only a few thousandths to several tenths of 1 percent) is increased in the juices of the plant, by the rapid evaporation of water from the leaves, to concentrations of several percent. The quantity of mineral elements in the tissues of plants is not uniform, however. Different species of plants and different organs of the same plant vary greatly in the content and composition of their mineral matter. Such variations are shown in table 4, which gives a selection (*471, pp. 127–128, 132–137*) of a few ash analyses of different crops.

Table 4.—***Ash analyses of different crops illustrating wide variations*[1] *in distribution of mineral constituents***

Crop	Samples	Pure ash in dry crop	Composition of pure ash of crop: Potash	Soda	Lime	Magnesia
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Meadow hay	106	6.98	26.71	3.70	15.95	6.89
		2.02-11.4	*7.6-56.6*	*.2-13.8*	*6.0-40.1*	*1.9-24.4*
Timothy grass	9	6.82	34.69	1.83	8.05	3.24
		5.1-9.3	*22.2-39.8*	*.3-3.1*	*4.7-15.6*	*2.3 5.5*
Red clover in bloom	113	6.86	32.29	1.97	34.91	10.90
		4.5-9 2	*8.8-52.0*	*0-8.9*	*21.9-53.4*	*5.3-26.1*
Alfalfa, beginning of bloom	12	7.38	23.55	1.76	40.67	4.92
		5.4-9.5	*11.4-41.9*	*.4-6.2*	*24.7 62.9*	*2.8-9.0*
Winter wheat, grain	110	1.96	31.16	2.07	3.25	12.06
		1.6-2.5	*23.2-41.1*	*0-9.1*	*.9-8.2*	*9.1-16.3*
Maize, grain	15	1.45	29.78	1.10	2.17	15.52
		1.0-1.7	*24.3-38.1*	*0-7.5*	*.6 3.8*	*12.1-18.1*
Peas	40	2.73	43.10	.98	4.81	7.99
		2.3-4.3	*35.8-51.8*	*0-3.6*	*1.8-7.9*	*3.7-13.0*
Garden beans	13	3.22	44.01	1.49	6.38	7.62
		2.9-4 0	*37.3-51.9*	*0-4.2*	*1.2-13.4*	*5.8-12.1*
Potatoes, tubers	59	3.79	60.06	2.96	2.64	4.93
		2.2-5.8	*44.0-73.6*	*0-17.5*	*.4-7.2*	*1.3-13.6*
Potatoes, vines	6	8.58	21.78	2.31	32.65	16.51
		5.2-12.9	*6.4-42.8*	*0-7.4*	*16.1-46.7*	*7.0-28.5*
Sugar beets, roots	149	3.83	53.13	8.92	6.08	7.86
		2.5-6.6	*26.9-78.1*	*0-24.0*	*1.6-17.8*	*2.3-11.9*
Sugar beets, leaves	25	14.88	26.26	13.75	20.20	11.33
		8.3-29.2	*12.6-44.2*	*2.7 30.8*	*5.7-32.3*	*6.8 20.5*
Grapes, entire fruit	7	5.19	56.20	1.42	10.77	4.21
		3.6-8.4	*42.6-66.5*	*.4 3.6*	*9.1-14.4*	*1.9 5.0*
Asparagus, young stalks	4	7.26	24.04	17.08	10.85	4.32
		5.5-10.5	*6.0-39.2*	*4.0-41.1*	*5.1 18 1*	*3.0-6 3*
Cabbage, heart	3	9.62	44.69	8.14	12.14	3.62
Cauliflower, heart	3	8.35	44.36	5.89	5.58	3.66
Spinach	2	16.48	16.56	35.29	11.88	6.38

Crop	Composition of pure ash of crop: Iron oxide	Phosphoric acid	Sulphuric acid	Silica	Chlorine
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Meadow hay	1.54	7.11	5.21	28.73	6.16
	.1-4.9	*2.0-21.3*	*.7-13.4*	*10.4-63.2*	*.2-21.4*
Timothy grass	.83	11.80	2.85	32.17	5.19
	.3-1.5	*5.5-19.1*	*1.9-5.1*	*21.5-44.5*	*2.4-13.1*
Red clover in bloom	1.08	9.64	3.23	2.69	3.78
	.3-5.0	*4.0-15.0*	*1.2-7.4*	*0-20.2*	*1.2-11.8*
Alfalfa, beginning of bloom	1.86	8.50	5.74	9.54	3.01
	.5-8.2	*4.5-19.3*	*3.7-8.6*	*.8-27.9*	*1.0-8.1*
Winter wheat, grain	1.28	47.22	.39	1.96	.32
	.1-3.0	*39.2-53.7*	*0-5.6*	*0-5.9*	*0-3.5*
Maize, grain	.76	45.61	.78	2.09	.91
	0-2.0	*37.6-53.7*	*0-4.1*	*0 5.5*	*0-4.8*
Peas	.83	35.90	3.42	.91	1.59
	0-3.8	*26.2-44.4*	*0-10.4*	*0-3.0*	*0-6.5*
Garden beans	.32	35.52	4.05	.57	.86
	0-.7	*27.1-46.6*	*1.4-6.4*	*0-1.7*	*0-2.3*
Potatoes, tubers	1.10	16.86	6.52	2.04	3.46
	0-7.2	*8.4-27.1*	*.4-14.9*	*0-8.1*	*.7-12.6*
Potatoes, vines	2.86	7.89	6.32	4.32	5.78
	1.8-4.3	*2.6-12.1*	*4.9-7.9*	*1.9-9.4*	*2.8-10.5*
Sugar beets, roots	1.14	12.18	4.20	2.28	4.81
	.2-4.9	*3.1-27.1*	*1.3-14.3*	*0-12.1*	*.2-18.4*
Sugar beets, leaves	.54	4.75	5.30	10.17	8.47
	0-2.4	*1.0-15.5*	*1.9-14.3*	*0-33.5*	*2.6-26.7*
Grapes, entire fruit	.37	15.58	5.62	2.75	1.52
	.1-1.3	*9.4-27.2*	*3.9-6.8*	*.6-5.1*	*.4-3.0*
Asparagus, young stalks	3.38	18.57	6.18	10.09	5.93
	.9-5.8	*13.8-21.9*	*4.1-7.9*	*.7-13.7*	*4.4-7.9*
Cabbage, heart	.45	11.89	13.69	.48	5.64
Cauliflower, heart	1.02	20.22	13.01	3.76	3.44
Spinach	3.35	10.25	6.87	4.52	6.20

[1] The second line of figures (italic) for each crop represents the range of analyses.

Since the ash obtained by incineration of plant materials contains the different mineral elements in the form of their oxides, the composition of the ash is so reported, although in the original plant material these elements existed in other forms as organic and inorganic compounds of unknown character. The high silica content of the ash of grasses; the high lime content of the ash of clover and alfalfa; the high potash and low lime content of the ashes of potato tubers and beet roots (as compared with the low potash and high lime content of the ashes of their vines and leaves); the high magnesia and high phosphoric acid content of the ashes of grains; and the high sulphuric acid content of the ashes of cabbages and cauliflower, are among the distinguishing characteristics that show the peculiar assimilating capacity of each species of plants for individual mineral constituents.

The extensive range in the percentages of each mineral component of crops (noted in table 4 in italics) indicates the wide fluctuations which the chemical composition of plant ashes may undergo under varying conditions. While some of these differences may be attributed to errors of sampling or analysis they are mostly the result of differences in (1) soil, (2) cropping, (3) variety of crop, (4) period of growth of crop, (5) climate, (6) water supply, (7) fertilizers, cultural practices, and other environmental conditions. Several of these influences will be considered in the following pages.

FACTORS INFLUENCING THE MINERAL COMPOSITION OF CROPS

Type of Soil

Because of other interfering factors, the influence of soil type upon the composition of the mineral constituents of crops can be determined only by making the comparisons with different soils under identical climatic and cultural conditions. This can be accomplished only by transferring the soils to a single locality, but when this is done it must be recognized that the results are not strictly comparable with those obtained with undisturbed soils in their original environment. Only a very limited number of experiments of this kind have been conducted for the purpose of correlating differences in yield, percentage of ash, and composition of the mineral matter of the crop with differences in the chemical composition of the soil. One of the most complete experiments performed in this connection is the duplicate one cited by Wolff (*471, pp. 15–16, 21*), in which crops of oats and buckwheat were grown alternately for 10 years without fertilization upon four different soils at Hohenheim, Germany, in walled pits 3 feet long, 2 feet wide, and 4 feet deep. A condensed summary of the results is given in table 5.

The loamy soil, containing the highest percentage of potash and phosphoric acid, produced oats the ashes of whose grain and straw were highest in these same ingredients. The descending percentages of potash in the four soils parallel the descending percentages of potash in the ashes of the green buckwheat plants and the oat straw. Similar correlations cannot be established, however, with the other ash ingredients. In fact, the humous soil of lowest magnesia content yielded products which contained the highest percentage of magnesia in the ash. This characteristic, observed also in other soils rich in humus (see muck soil of table 9, p. 786), is probably due to a more ready availability of the magnesia to the plant. The highest average yield of grain was obtained on the loamy soil, the highest average yield of straw on the humous soil, and the highest average yield of green buckwheat on the clayey soil. The crop yields in these experiments were lowest on the sandy soils, where the percentage of ash in the crop was also lowest. Ordinarily, however, there is no relationship between ash content and yield of crop. Subsequent tables (tables 9, 12, and 14) show how differences in soils affect the composition of the mineral matter of crops in other ways.

Table 5.—*Effect of different soils on composition of oats and buckwheat*

COMPOSITION OF SOILS

Type of soil	Moisture	Loss on ignition	Potash	Lime	Magnesia	Phosphoric acid
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Loamy	11.12	3.73	2.07	0.82	0.68	0.10
Clayey	9.03	4.83	1.97	.84	.78	.09
Sandy	10.67	2.63	1.53	.59	.41	.05
Humous	29.09	14.98	.90	.43	.31	.09

COMPOSITION OF GRAIN OF OATS[1]

	Dry yield	Ash content				
	Grams	*Percent*				
Loamy	320	2.96	20.60	3.18	6.72	29.78
Clayey	311	2.82	18.87	3.07	6.78	28.31
Sandy	228	2.65	19.08	3.05	6.88	24.57
Humous	305	3.03	19.15	3.08	7.46	27.61

COMPOSITION OF STRAW OF OATS[2]

Loamy	587	8.07	26.94	6.36	2.87	3.93
Clayey	519	8.07	23.82	5.56	2.67	2.74
Sandy	386	6.38	24.19	5.82	3.54	2.75
Humous	754	7.48	22.73	7.18	4.94	2.98

COMPOSITION OF GREEN BUCKWHEAT PLANTS[3]

Loamy	329	7.98	38.64	32.44	12.61	8.14
Clayey	338	9.24	33.29	42.49	12.17	3.83
Sandy	219	7.46	26.64	49.71	9.85	3.90
Humous	251	7.79	26.47	37.72	16.61	8.53

[1] Ingredients in total ash of grain; average of 5 years.
[2] Ingredients in total ash of straw; average of 5 years.
[3] Ingredients in total ash of plant; average of 4 years.

Continuous Cropping

The continued cultivation of crops on the same soil without addition of fertilizers causes a gradual depletion of the supplies of available plant food with corresponding reductions in yield and changes in composition of the mineral matter of the plant. Potassium is the element that is most freely absorbed by plants from the soil and the one whose deficiency is most quickly reflected by changes in the composition of the plant ash. This is shown in table 6, which is compiled from the experiment at Hohenheim (*471*), to which reference has just been made. The results obtained on each of the four soils have been averaged together so as to obtain the composite effect of cropping for each year of the experiment.

The results of table 6 indicate that the effects of cropping upon yield and composition are much less noticeable with buckwheat than with oats. The yields of grain and straw of oats declined in the 10 years to approximately one-third of the original amount, and the potash in the ash diminished to eight-tenths of its original amount in the grain and to three-tenths of its original amount in the straw. With the diminishing percentage of potash in the various ashes there was a corresponding slight increase in the percentages of lime and magnesia. The complementary relationship of potash to lime and magnesia is seen also in the fluctuations in composition of the ash of the buckwheat. Observations of this nature caused Liebig (*218*) to announce his law of replaceability in accordance with which an alkali or alkaline earth that is lacking in any soil is supplied by one similar in its mode of action. This doctrine is true, however, only within certain limits, for no

element necessary to the process of vegetation can be wholly replaced by another. Other observations as to the effects of continuous cropping upon the mineral composition of plants will be referred to later.

Table 6.—*Effects of continuous cropping on the yield, ash content, and composition of the mineral matter of oats and buckwheat*

GRAIN OF OATS[1]

Year	Yield of dry matter	Ash content	Ingredients in total ash: Potash	Lime	Magnesia	Phosphoric acid
	Grams	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1869	441	2.86	22.04	2.39	7.37	29.02
1873	271	2.91	22.85	2.27	6.33	26.48
1875	345	2.71	18.28	2.81	6.85	27.97
1877	258	2.70	16.51	4.06	8.31	27.22
1879	141	3.16	17.46	3.95	6.98	27.16

STRAW OF OATS[1]

Year	Yield of dry matter	Ash content	Potash	Lime	Magnesia	Phosphoric acid
1869	946	8.09	37.38	3.95	2.41	2.62
1873	613	7.45	39.36	4.52	2.66	2.70
1875	538	6.95	18.38	6.02	3.37	2.78
1877	380	7.04	15.29	8.07	9.78	3.39
1879	380	7.99	11.69	8.60	4.31	4.01

GREEN BUCKWHEAT[2]

Year	Yield of dry matter	Ash content	Potash	Lime	Magnesia	Phosphoric acid
1872	355	7.50	35.26	37.72	12.35	6.95
1874	270	7.56	27.90	41.88	13.32	5.24
1876	222	9.02	27.22	42.42	13.94	6.15
1878	293	8.39	34.67	40.33	11.62	6.07

[1] Averages of crops on 4 different soils for 5 different years.
[2] Averages of crops on 4 different soils for 4 different years.

Variety of Crop

Different varieties of wheat, corn, potatoes, peas, sugarcane, and other crops when grown upon the same soil may show sometimes as great differences in the composition of their mineral components as plants of entirely unrelated species. In table 7, from results of Mach and Herrmann (*230*), it will be noted that while the vines of the Odenwälder and Gisevius potatoes yielded nearly equal amounts of mineral matter the respective percentages of lime in these ashes were 50.96 and 29.96, a difference in ratio of 5 to 3. There was three times as much potash in the ash of the vines of the Gisevius variety as in that of the vines of the Industry variety. In the case of the ash of the tubers it will be noted that while all three varieties yielded almost identical amounts of ash there were notable differences in the percentages of potash, lime, magnesia, and phosphoric acid.

The percentages of mineral matter in the dry substance of the stalks and tops of 12 different varieties of sugarcane with the percentages of potash, lime, and phosphoric acid in the mineral matter and the weights of these components removed per acre are given in table 8 according to analyses reported in 1905 by Eckart (*99*), of the Hawaiian Sugar Planters' Experiment Station. The results are based on the analyses of varieties grown under identical conditions, as far as they could be obtained, with regard to climate, soil, cultivation, irrigation, and fertilization. The variations in composition are, therefore, due to differences in the demands made by the several varieties on the mineral constituents of the soil.

Table 7.—*Analyses of the ashes of the vines and tubers of 3 varieties of potatoes grown in the same locality, in the same year, on the same soil, under similar conditions of fertilization, cultivation, weather, and harvest*

Variety		Total mineral content	Composition of ash			
			Potash	Lime	Magnesia	Phosphoric acid
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Odenwälder Blue	vines	10.93	6.68	50.96	7.59	2.92
Industry	do	9.69	3.71	49.63	10.11	2.78
Gisevius	do	11.08	11.55	29.96	10.55	2.70
Odenwälder Blue	tubers	4.39	50.34	1.14	4.78	6.83
Industry	do	4.39	50.11	3.64	6.15	7.29
Gisevius	do	4.32	52.08	1.39	5.32	9.95

Table 8.—*Percentages and composition of mineral matter of stalks and tops of 12 varieties of sugarcane with weights of potash, lime, and phosphoric acid removed per acre*

Stalks

Variety	Mineral matter		Composition of mineral matter			Weight removed per acre		
	In dry substance	Weight per acre	Potash	Lime	Phosphoric acid	Potash	Lime	Phosphoric acid
	Percent	*Pounds*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*
Cavengerie	2.90	1,456	30.29	4.54	11.82	441	66	172
Gee Gow	2.14	606	17.36	3.16	10.72	105	19	65
Louisiana Purple	2.20	879	32.27	2.64	16.37	284	23	144
Queensland 1	2.63	1,142	21.78	4.41	9.67	249	51	110
Queensland 4	2.49	821	25.52	3.16	15.40	210	26	126
Demerara 74	3.69	1,410	37.14	1.58	13.25	524	22	187
Demerara 95	2.39	713	32.18	2.15	14.26	229	15	102
Demerara 117	2.48	1,311	27.81	1.54	19.60	364	20	257
Yellow Bamboo	3.01	784	39.15	1.44	16.16	307	11	127
White Bamboo	3.35	1,290	25.95	4.19	14.26	335	54	184
Yellow Caledonia	3.56	1,509	31.95	3.15	12.30	482	48	186
Striped Singapore	2.60	1,041	39.54	2.34	12.03	412	24	125
Average	2.79	1,080	30.08	2.86	13.82	328	32	119

Tops, leaves, and dead cane

Variety	Mineral matter		Composition of mineral matter			Weight removed per acre		
	In dry substance	Weight per acre	Potash	Lime	Phosphoric acid	Potash	Lime	Phosphoric acid
	Percent	*Pounds*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*
Cavengerie	8.47	5,288	15.85	4.83	2.53	838	255	134
Gee Gow	8.41	5,266	16.83	4.44	3.97	879	232	207
Louisiana Purple	8.78	5,729	22.01	4.88	3.80	1,261	280	218
Queensland 1	9.23	6,796	15.75	4.94	1.58	1,070	336	107
Queensland 4	7.82	4,168	15.22	4.54	1.10	634	189	46
Demerara 74	8.04	4,408	25.17	3.69	4.64	1,109	163	205
Demerara 95	9.04	4,743	17.60	5.24	3.24	835	249	154
Demerara 117	11.31	5,412	16.16	5.74	1,42	875	311	77
Yellow Bamboo	7.27	3,001	14.09	4.78	2.98	423	143	89
White Bamboo	6.56	2,877	13.33	6.41	1.62	384	184	47
Yellow Caledonia	8.22	3,460	15.85	5.46	2.23	548	189	77
Striped Singapore	8.28	5,081	20.37	5.69	2.48	1,035	289	126
Average	8.45	4,686	17.35	5.05	2.63	824	235	124

Table 8.—*Percentages and composition of mineral matter of stalks and tops of 12 varities of sugarcane with weights of potash, lime, and phosphoric acid removed per acre*—Continued

Ingredient	Ranges of composition	
	Stalks	Tops, leaves, etc.
	Percent	*Percent*
Ash in dry matter of crop	2.14– 3.56	6.56–11.31
Potash (K_2O) in ash of crop	17.36–39.54	13.35–22.01
Lime (CaO) in ash of crop	1.41– 4.54	3.69– 6.41
Phosphoric acid (P_2O_5) in ash of crop	9.67–19.60	1.10– 4.64

Comparative Influences of Crop Variety and of Soil

While different varieties of the same crop show marked differences in composition of their mineral matter when grown on the same soil, the relationships between the mineral components of a given variety are profoundly changed when it is grown upon other soils. This is shown in some recent unpublished analyses by N. McKaig, Jr., and C. A. Fort, of the Department of Agriculture, of the ashes of the juices of five different sugarcane seedlings (first ratoons) grown on four different Florida soils. A partial summary of the results is given in table 9.

Table 9.—*Comparative influences of crop variety and of soil upon the yield and composition of the ash of sugarcane juice*

Variety of sugarcane first ratoons	Results on custard apple muck soil					Average results on hammock land, marl, and calcareous soils				
	Ash in juice	Percent of total ash				Ash in juice	Percent of total ash			
		Potash	Lime	Magnesia	Phosphoric acid		Potash	Lime	Magnesia	Phosphoric acid
	Percent	*Percent*	*Percnet*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
POJ 36	2.34	18.68	11.28	20.13	5.26	2.72	38.08	12.95	7.06	14.41
POJ 213	1.89	32.49	8.31	19.31	4.55	2.32	33.72	15.86	6.78	15.95
POJ 234	1.87	31.12	10.96	17.64	4.55	2.02	36.83	13.76	9.01	14.26
Co 281	2.57	20.47	17.16	17.12	3.50	3.17	47.46	10.62	5.03	11.76
CP 807	2.30	20.00	10.21	28.48	6.04	2.92	39.23	11.51	7.83	15.50
Average:										
Muck soil	2.19	24.55	11.58	20.54	4.78					
Hammock land	2.33	48.55	6.58	6.64	27.31					
Marl	3.18	29.37	18.37	9.55	10.09					
Calcareous	2.56	40.82	12.78	5.66	5.11					

Variety of sugarcane first ratoons	Averages according to varieties on all soils				
	Ash in juice	Percent of total ash			
		Potash	Lime	Magnesia	Phosphoric acid
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
POJ 36	2.63	32.87	12.85	10.32	12.58
POJ 213	2.21	33.22	14.46	11.29	13.07
POJ 234	1.98	34.87	13.57	10.89	10.71
Co 281	3.25	40.09	12.62	7.43	8.79
CP 807	2.77	34.42	11.60	12.34	13.47

Ratio of ranges in percentage composition of ash $\frac{\text{Soil basis}}{\text{Variety basis}}$:

For potash (K_2O) $\frac{48.55-24.55}{40.09-32.87}=3.3.$

For magnesia (MgO) $\frac{20.54-5.66}{12.34-7.43}=3.0.$

For lime (CaO) $\frac{18.37-6.58}{14.46-11.60}=4.1.$

For phosphoric acid (P_2O_5) $\frac{27.31-4.78}{13.47-8.79}=4.8.$

For total ash $\frac{3.18-2.19}{3.25-1.98}=0.78.$

The average percentage of ash in the cane juices from the hammock, marl, and calcareous soils is much higher than that in the corresponding juice of the same variety from the muck soil. The general quantitative relationship of the ashes of the different varieties is, however, alike, seedling 281, for example, ranking highest in percentage of ash in both cases and seedling 234 lowest. The individual percentages of potash, lime, magnesia, and phosphoric acid in the ashes show, however, no similarity in the two cases; the influence of the muck soil in lowering the percentages of potash and phosphoric acid and in increasing the percentage of magnesia completely eliminates any varietal effects observed in the average results on the other three soils. The respective influences of soil and variety in these experiments are shown by comparing the combined averages for each of the five varieties on the four different soils and the combined averages for each of the four different soils on which the five varieties were grown. The ranges in percentages of potash, lime, magnesia, and phosphoric acid when the comparisons are made according to soil are over three times greater than when the comparisons are made according to variety, thus indicating in the case of these experiments the greater preponderating influence of soil over variety. With respect to the percentage of total mineral matter in the cane juice, the varietal effect, however, is somewhat greater than that of soil.

Successive Cuttings of Crops Grown on the Same Soil

The mineral content of successive cuttings of the same plant is a question of considerable importance in considering the nutritive value of grass and hay crops. The results of table 10, taken from the tabulations of Mach and Herrmann (*230*), show the marked variations that occur in the potash, lime, magnesia, and phosphoric acid content of the ash of first, second, and third cuttings of lucerne grown in successive years at Harleshausen, Germany, upon a diluvial loam. Fifty kilograms of phosphoric acid as Thomas meal and 80 kilograms of potash as 40-percent potash salt were applied each year as fertilizers.

Table 10.—*Influence of successive years and cuttings upon the potash, lime, magnesia, and phosphoric acid content of the ash of Frankish lucerne*

Year	Cutting	Ash	Mineral content			
			Potash	Lime	Magnesia	Phosphoric acid
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
1928	First	10.52	21.10	16.82	3.99	5.42
	Second	10.28	15.08	21.11	3.89	5.93
	Third	10.84	16.42	23.71	3.88	4.52
1929	First	11.43	42.43	15.66	4.46	5.34
	Second	11.46	28.71	22.51	3.84	5.76
	Third	9.95	18.19	24.92	4.22	4.32

The successive cuttings show a marked reduction in the potash content and a considerable increase in the lime content of their ashes as compared with previous cuttings of the same year. The percentage of phosphoric acid in the ash of the second cuttings shows a slight increase above that in the first, whereas there is a marked decrease in the ash of the third cuttings as compared with that of the first and second.

With irrigated alfalfa at different stages of maturity, Sotola (*374*) obtained results (table 11) for the calcium and phosphorus content of successive cuttings that are somewhat at variance with the findings in table 10. The average of Sotola's results for 2 years showed less calcium and more phosphorus in the second cutting as compared with the first and more calcium and less phosphorus in the third cutting as compared with the second. Such variations indicate the marked sensitiveness of crops to variations in the composition of their mineral matter with slight changes in environmental conditions.

Table 11.—*Effect of the stage of maturity and the number of the cuttings on the calcium and phosphorus content of alfalfa*

' percent moisture basis]

Stage of maturity and cutting	Calcium			Phosphorus		
	1923	1924	Average	1923	1924	Average
One-fourth bloom:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
First	1.371	1.234	1.30	0.164	0.145	0.154
Second	1.331	1.025	1.178	.203	.177	.190
Third	1.174	1.416	1.295	.148	.218	.183
Average	1.292	1.225	1.258	.172	.180	.176
One-half bloom:						
First	1.610	1.347	1.478	.162	.145	.154
Second	1.392	1.196	1.294	.190	.169	.180
Third	1.354	1.546	1.450	.176	.114	.145
Average	1.452	1.363	1.407	.176	.143	.160
Three-fourths bloom:						
First	1.449	1.326	1.388	.138	.165	.152
Second	1.352	1.189	1.270	.142	.126	.134
Third	1 312	1.240	1.276	.093	.106	.100
Average	1.371	1.252	1 311	.124	.132	.129

Influence of Climate on Crops Grown on the Same Soil

In many cases climatic conditions, such as temperature, humidity, rainfall, sunshine, and altitude, are the dominating factor in controlling the composition of the mineral matter of crops. While plants are dependent upon the soil for their mineral nutrients, climatic conditions so affect respiration, assimilation, photosynthesis, metabolism, and other physiological processes, that the composition of both the mineral and organic matter of crops may be greatly modified even though they are grown upon identical soils. This is well illustrated by several trilocal soil-exchange experiments with wheat, conducted by LeClerc and Yoder of the Bureau of Chemistry in 1909 to 1911 (*215*). Three samples of soil 5 feet square and 3 feet deep, at College Park, Md., Hays, Kans., and Davis, Calif., were dug up at each locality in 3-inch layers, sacked, exchanged with soils from the two other localities and then replaced with layers in the same original positions. The three plots thus prepared in each locality were then sown with the same variety of wheat and the resultant crops harvested and analyzed. A few results of the 1910 crop are shown in table 12, where the analyses are averaged according to soils and according to localities.

The wheat grown on Maryland soil in Kansas contained 6.13 percent more protein and 5.01 percent more potash in its ash than the wheat grown on Maryland soil in Maryland, while the wheat grown on Kansas soil in Kansas contained 7.88 percent more protein and 5.96 percent more potash in its ash than the wheat grown on Kansas soil in Maryland. On the other hand the wheat grown on Maryland soil in Maryland yielded 0.25 percent more ash and 13.81 percent more phosphoric acid in its ash than the wheat grown on Maryland soil in Kansas. The wheats grown on the three soils in California gave average values for protein and percentages of potash and phosphoric acid in ash intermediate between the average values obtained for wheats grown on the same three soils in Maryland and Kansas. Comparisons upon the basis of the average value for the same soil in different localities show that the Maryland soil gave wheats with the greatest amounts of protein and ash and the highest percentages of phosphoric acid in the ash. The values resulting from comparing the ratio of maximum less minimum of soil factor to the maximum less minimum of the similar locality factor indicate that the influence of locality or climate is 3.3 percent stronger for protein, 1.8 stronger for ash, 2.4 stronger for phosphoric acid in ash and 3.2 stronger for potash than the similar influences of soil under the conditions of this trilocal

experiment. In studies of this kind it must be borne in mind that soils originally identical do not develop alike in physical and chemical properties under different climatic conditions.

Table 12.—***Protein content, yield of ash, and percentages of phosphoric acid and potash in ash of Turkey wheat grown on three exchange soils in widely separated States in 1910***

[Percentages of water-free substance]

GROUPING ACCORDING TO SOILS

Item	Wheat grown on California soil in—				Wheat grown on Kansas soil in—			
	California	Kansas	Maryland	Average	California	Kansas	Maryland	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Protein	13.63	15.98	10.27	13.29	10.60	18.73	10.85	13.39
Ash	1.84	1.99	2.09	1.97	1.82	1.97	2.07	1.95
P_2O_5 in ash	42.93	43.22	Lost	43.08	47.25	41.11	52.65	47.00
K_2O	33.15	30.65	Lost	31.90	30.22	33.50	27.54	30.42

Item	Wheat grown on Maryland soil in—				Range of averages
	California	Kansas	Maryland	Average	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Protein	16.28	17.81	11.68	15.26	1.97
Ash	2.05	1.97	2.22	2.08	.13
P_2O_5 in ash	49.75	40.61	54.50	48.29	5.21
K_2O	31.70	32.49	27.48	30.56	1.48

GROUPING ACCORDING TO LOCALITIES

Item	Wheat grown in California on soil from—				Wheat grown in Kansas on soil from—			
	California	Kansas	Maryland	Average	California	Kansas	Maryland	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Protein	13.63	10.60	16.28	13.50	15.98	18.73	17.81	17.51
Ash	1.84	1.82	2.05	1.90	1.99	1.97	1.97	1.98
P_2O_5 in ash	42.93	47.25	49.75	46.64	43.22	41.11	40.61	41.31
K_2O	33.15	30.22	31.70	31.69	30.65	33.50	32.49	32.31

Item	Wheat grown in Maryland on soil from—				Range of averages
	California	Kansas	Maryland	Average	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Protein	10.27	10.85	11.68	10.93	6.58
Ash	2.09	2.07	2.22	2.13	.23
P_2O_5 in ash	Lost	52.65	54.50	53.58	12.27
K_2O	Lost	27.54	27.48	27.51	4.80

Ratio of $\frac{\text{Influence of locality}}{\text{Influence of soil}}$:

For protein $\frac{6.58}{1.97}=3.3$. For phosphoric acid (P_2O_5) $\frac{12.27}{5.21}=2.4$.

For ash $\frac{0.23}{0.13}=1.8$. For potash (K_2O) $\frac{4.80}{1.48}=3.2$.

The influence of climate may prevail over that of soil in localities only a few miles apart. This is illustrated in a soil exchange experiment with sugarcane conducted by Borden at the Hawaiian Sugar Planters' Experiment Station in 1935 (*40*). The two localities for this experiment, although only 3½ miles apart, differed markedly in climatic conditions, as shown by table 13.

Table 13.—*Differences between two localities in Hawaii 3½ miles apart*

Item	Makiki	Manoa
Elevation ... feet	40	550
Rainfall ... inches	46.96	198.94
Temperature range ... °F	67.5–84.6	67.4–80.2

The sunshine received at Manoa is approximately 40 percent less than that received at Makiki. Tubs of earth from a fertile field at Makiki and from a supposedly poor soil at Manoa were planted with three different varieties of sugarcane, which were allowed to grow at both Makiki and Manoa for 14 months. The canes were then cut and topped, the stalks weighed and crushed, and the juice analyzed. An abstract of the results is presented in table 14.

Table 14.—*Influence of climatic conditions in two localities upon the composition of three varieties of sugarcane grown on two different soils*

Variety of cane	Soil	Sugar produced			Phosphoric acid in 100 cc of juice			Potash in 100 cc of juice		
		At Makiki	At Manoa	Difference in favor of Makiki	At Makiki	At Manoa	Difference in favor of Manoa	At Makiki	At Manoa	Difference in favor of Manoa
		Pounds	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
H 109	Makiki	10.63	3.37	7.26	0.078	0.085	0.007	0.18	0.22	0.04
	Manoa	12.14	2.54	9.60	.014	.021	.007	.05	.15	.10
Striped Tip	Makiki	4.47	3.46	1.01	.128	.134	.006	.26	.27	.01
	Manoa	8.38	2.93	5.45	.046	.061	.015	.08	.12	.04
POJ 2878	Makiki	8.64	1.87	6.77	.082	.099	.017	.31	.27	–.04
	Manoa	9.34	2.19	7.15	.024	.026	.002	.09	.21	.12
Average		8.93	2.73	6.20	.062	.071	.009	.162	.207	.045

A reclassification of the results shown in table 14 on a soil and on a variety basis is shown in table 15.

Table 15.—*Reclassification of results shown in table 14*

Item	Soil basis—averages for 3 varieties in both localities		Variety basis—averages for 2 soils in both localities		
	Makiki soil	Manoa soil	H 109	Striped Tip	POJ 2878
Average sugar produced ... pounds	5.41	6.26	7.17	4.81	5.51
Average phosphoric acid in 100 cc of juice ... percent	.101	.032	.050	.092	.058
Average potash in 100 cc of juice ... do	.25	.12	.15	.18	.22

When grown on identical soils the canes at Makiki produced over three times as much sugar as the canes at Manoa (fig. 1), thus indicating the dominant effect in the case of sugar production of climate over soil. With respect to phosphoric acid and potash in the juice, the differences with one exception were all in favor

FIGURE 1.—Effect of climate on growth of sugarcane: H 109 cane grown with ample fertilization on "poor" Manoa soil at Makiki on left and at Manoa on right. (Courtesy Hawaiian Sugar Planters' Experiment Station.)

of the canes grown at Manoa, the average increase being 1.145 times for phosphoric acid and 1.277 times for potash, so that the importance of climate in influencing the mineral composition of crops is again clearly indicated. While the climatic influence in this experiment is dominant in the case of sugar production, the influence of soil predominates in the effect upon the content of phosphoric acid and potash in the juice. A reclassification of the results according to variety of cane shows that the juice of POJ 2878 contained the highest content of potash and that of Striped Tip the highest content of phosphoric acid.

Water Supply

A very important factor in influencing the mineral composition of crops is water supply, whether from rain or irrigation. As a general rule increasing the water supply increases the absorption of mineral matter from the soil. This is shown in the experiments of Borden (*40*) in which the sugarcanes grown at Manoa with a rainfall of 199 inches showed a much greater amount of phosphoric acid and potash in the juice than the same varieties of cane grown on identical soils at Makiki with a rainfall of only 47 inches.

The effects of water supply in increasing the mineral content of crops are shown even more markedly in irrigation experiments. This is illustrated by the results of table 16, taken from the work of Greaves and Carter of the Utah Agricultural Experiment Station (*131*).

The soil on which these cereals were grown was "a very productive calcareous loam of sedimentary origin. The surface acre-foot contained 4,904 pounds of total nitrogen, 2,700 pounds of total phosphorus, 60,560 pounds of total potassium, 434,365 pounds of acid soluble calcium, and 132,463 pounds of acid soluble magnesium."

With progressive additions of irrigation water, increases occur in the percentages of ash, potassium, calcium, magnesium, and phosphoric acid in the grain of wheat, oats, and barley. But beyond certain limits, usually above 35 inches, there was a decrease in some of these values, the extent of this decrease varying with the different cereals. In opposition to this effect of increasing the mineral content of the grain of the three cereals, increase of irrigation was found in general to reduce the nitrogen or protein content. Of the three cereals, oats removed the most pounds of ash, potassium, and magnesium per acre, wheat the most pounds of phosphorus, and barley the most pounds of calcium.

With regard to the nutritive value of grain grown upon irrigated soils Greaves and Carter make the following comment:

"For the feeding of farm animals in which the production of bone is considered the irrigated grain would be superior. Whether or not watered grain would be more valuable in the bread of man would depend upon whether the milling process were leaving the same quantities of ash in the watered grain and whether the excess of ash were more valuable than the excess of protein in the non-irrigated grain. Individuals in need of more ash in the diet could well turn to the irrigated grains in preference to the non-irrigated, although by so doing they would be getting less protein, and conversely where it is desired to restrict the mineral intake of an individual the nonirrigated grain should be used.

"Considering the extent to which irrigation water has modified the mineral elements in these grains it is easy to see how a ration of irrigated cereals would carry sufficient calcium and phosphorus if fed to swine to produce strong normal bones, which is not the case with corn alone. Moreover, it is possible that the variations sometimes obtained by different feeders may be correlated with this large variation in ash content of grains grown under different conditions of irrigation.

"Moreover, there may be cases where human individuals are living on restricted diets in which the greater quantities of minerals contained in the irrigated grains may be sufficient to prevent nutritional disorders that may occur where the dry farm grains are used."

Results similar to those reported for wheat, oats, and barley were obtained by Greaves and Nelson (*132*) in the irrigation of corn. The authors attribute the increased content of mineral matter in irrigated grain to an intensified bacterial activity which increases the available plant food of the soil. The increased transpiration of water through the leaves of the irrigated plants would also convey more soluble mineral constituents from the soil to the plant.

Table 16.—*Percentages and amounts per acre of total ash, potassium, calcium, magnesium, and phosphorus found in the grain of wheat, oats, and barley grown with varying quantities of irrigation water*

Water applied (inches)	Wheat		Oats		Barley	
	Percent	*Pounds*	*Percent*	*Pounds*	*Percent*	*Pounds*
ASH						
None	1.561	35.12	3.344	48.79	2.366	29.86
5	1.561	34.17	3.524	65.67	2.329	32.03
10	1.568	35.90	3.597	74.27	2.332	38.07
15	1.711	36.38	3.664	87.92	2.723	48.51
20	2.015	38.45	3.606	81.81	2.810	51.54
35	2.284	51.13	4.288	110.70	2.978	58.31
45	-----	-----	4.390	106.30	-----	-----
52.5	-----	-----	-----	-----	3.228	59.98
67.5	2.194	47.13	-----	-----	-----	-----
POTASSIUM						
None	0.3965	8.92	0.4176	6.09	0.3886	4.90
5	.4137	8.97	.4833	8.12	.4007	5.47
10	.4395	9.49	.4827	9.68	.4467	7.22
15	.4915	10.47	.4736	11.17	.4773	7.24
20	.4902	9.35	.4741	10.74	.5462	10.02
35	.5340	11.95	.5212	13.46	.5159	10.10
45	-----	-----	.5461	13.23	-----	-----
52.5	-----	-----	-----	-----	.4413	8.26
67.5	.5351	11.50	-----	-----	-----	-----
CALCIUM						
None	0.1027	2.31	0.1464	2.14	0.1066	2.80
5	.1072	2.02	.1480	2.88	.1029	2.95
10	.1221	2.63	.1679	3.54	.1034	3.28
15	.1651	3.53	.1668	3.60	.1069	4.19
20	.1951	3.78	.1783	4.04	.1020	3.89
35	.2106	4.72	.1598	4.13	.1448	5.90
45	-----	-----	.1356	3.28	-----	-----
52.5	-----	-----	-----	-----	.1502	5.81
67.5	.2625	5.61	-----	-----	-----	-----
MAGNESIUM						
None	0.1698	3.82	0.1319	1.92	0.1794	2.26
5	.1708	3.54	.1639	2.77	.1770	2.42
10	.1718	3.65	.1742	3.47	.1776	2.86
15	.1724	3.23	.1743	3.91	.1863	2.95
20	.1978	3.77	.1721	3.90	.1950	3.58
35	.2070	4.64	.1949	5.03	.1709	3.35
45	-----	-----	.2181	5.28	-----	-----
52.5	-----	-----	-----	-----	.1852	3.44
67.5	.2236	4.80	-----	-----	-----	-----
PHOSPHORUS						
None	0.2953	6.64	0.2793	4.07	0.3090	3.90
5	.3011	6.38	.2870	5.84	.3024	4.30
10	.3059	6.38	.3131	6.23	.3001	4.70
15	.3233	6.87	.3182	7.51	.3158	5.59
20	.3710	7.08	.3400	7.71	.3349	6.14
35	.4578	10.24	.3782	9.77	.4023	7.88
45	-----	-----	.3690	8.94	-----	-----
52.5	-----	-----	-----	-----	.3752	6.97
67.5	.4245	9.12	-----	-----	-----	-----

Fertilizers

The influence of fertilizers upon the composition of the mineral matter of crops is exceedingly complex, for not only do the variable effects of variety of crop, climate, water supply, and other environmental conditions apply to the fertilizers incorporated with soils, but there is also the additional complication of the influence which the presence of one element exercises upon the absorptive powers of the plant for other mineral nutrients of the soil or fertilizer. Many illustrations of this could be given but only a few examples will be cited.

The influence of ammonium sulphate upon the yield of wheat and upon the ash, phosphoric acid, potash, lime, magnesia, and silica content of its straw and grain is shown in table 17 from the 16-year average of results obtained at Rothamsted by Russell (*331, p. 70*) between the years 1848 and 1863.

Table 17.—*Effect of nitrogen supply on nitrogen, ash, and mineral content of wheat*

Portion of crop and quantity of nitrogen [1] applied per acre	Yield per acre	Composition of dry matter					
		Nitrogen	Ash	Potash	Lime	Magnesia	Phosphoric acid
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Straw:							
None	1,663	0.50	6.44	0.93	0.25	0.13	0.21
86 pounds	2,663	.67	5.32	.87	.32	.09	.16
Grain:							
None	990	1.90	2.01	.66	.06	.03	1.00
86 pounds	1,525	2.15	1.80	.60	.07	.19	.85

The application of ammonium sulphate, while greatly increasing the yield of both straw and grain, caused a decrease in their total mineral matter and in their percentages of potash and phosphoric acid. At the same time there was a slight increase in the lime content of both straw and grain, a marked increase in the magnesia content of the grain, and a decrease in the magnesia content of the straw. These conclusions do not always apply, however, to other crops or to other conditions of climate and environment.

Table 18.—*Average composition of the herbage of the grass plots at Rothamsted, 1856–73*

Mineral constituent	Nitrogenous fertilizers		No nitrogenous fertilizers	
	Nitrogen and phosphorus (no potash), plot 4–2	Nitrogen, phosphorus, and potash, plot 9	Phosphorus only (no potash), plot 4–1	Phosphorus and potash, plot 7
In dry matter:	*Percent*	*Percent*	*Percent*	*Percent*
Potash (K_2O)	0.98	2.58	1.32	2.77
Soda (Na_2O)	.59	.28	.56	.12
Lime (CaO)	.91	.60	1.17	.96
Phosphoric acid (P_2O_5)	.72	.58	.65	.64
Ash	6.18	7.24	7.23	8.02
Nitrogen (N)	1.95	1.55	1.58	1.74
In ash:				
Potash (K_2O)	15.80	35.59	18.26	34.60
Soda (Na_2O)	9.52	3.87	7.68	1.53
Lime (CaO)	14.70	8.27	16.22	11.92
Phosphoric acid (P_2O_5)	11.58	7.96	8.93	7.92

The influence of potassium salts, when added as fertilizer to soils is in general to increase the total ash and potash content of crops and to lower the percentages of the other ash constituents. This is shown in the average composition of grass grown at Rothamsted during the 18-year period 1856–73, upon soils fertilized with and without potash (table 18) (*331, p. 93*).

The effects of the application of phosphates upon the assimilation of mineral nutrients by crops are more variable owing to a number of complicating factors. Phosphoric acid is occasionally fixed by the soil in nonsoluble combinations (such as phosphate of iron) that are not easily assimilated by the crop. Silica, soil reaction, and other factors also affect the rate of assimilation of phosphoric acid. Usually in cases of deficiency the influence of added phosphate is to increase the percentage of phosphoric acid in the ash and dry matter of the crop, and frequently to produce a decrease in the assimilation of some of the other nutrients, but so much depends upon the character of the soil, water supply, variety and stage of growth of crop, climatic conditions, and other factors that no general rule can be formulated.

The mutual effects of all the various soil nutrients on the yield of crops and their assimilation of mineral matter under different environmental conditions are so complicated that the literature on the subject presents a chaos of contradictions. The operations of the so-called law of the minimum and of the law of diminishing returns enter into all the discussions of this and other related problems.

Table 19.—*Influence of balance of fertilizer treatment upon nitrogen, potash, and phosphoric acid content of grapevine leaves, 1925*

Date	Treatment					Mineral content of dry vine leaves			Relative yield of grapes
	No.	Fertilizer	Mineral composition						
			Nitrogen (N)	Potash (K_2O)	Phosphoric acid (P_2O_5)	Nitrogen (N)	Potash (K_2O)	Phosphoric acid (P_2O_5)	
			Kilogram	*Kilogram*	*Kilogram*	*Percent*	*Percent*	*Percent*	*Percent*
May 16	1	None				1.98	1.66	0.50	
	2	Balanced	80	90	75	2.59	1.98	.80	
	3	Unbalanced	80	90		3.85	2.39	.43	
	4	do.	80		75	2.75	1.60	1.05	
June 17	1	None				1.65	1.39	.32	
	2	Balanced	80	90	75	2.15	1.71	.70	
	3	Unbalanced	80	90		3.15	2.16	.27	
	4	do.	80		75	2.15	1.26	.76	
July 17	1	None				1.50	1.50	.26	
	2	Balanced	80	90	75	1.95	1.66	.50	
	3	Unbalanced	80	90		2.65	1.46	.19	
	4	do.	80		75	1.75	1.31	.56	
Aug. 14	1	None				1.20	1.45	.14	
	2	Balanced	80	90	75	1.30	1.73	.36	
	3	Unbalanced	80	90		2.00	1.58	.16	
	4	do.	80		75	1.35	1.05	.38	
Sept. 15	1	None				1.35	.83	.13	
	2	Balanced	80	90	75	1.75	1.80	.25	
	3	Unbalanced	80	90		2.05	1.41	.12	
	4	do.	80		75	1.40	.95	.24	
Oct. 16	1	None				.95	.53	.15	81.5
	2	Balanced	80	90	75	1.05	1.10	.30	100.0
	3	Unbalanced	80	90		1.35	.88	.17	60.0
	4	do.	80		75	1.25	.48	.35	59.3

[1] Per hectare.

Sprengel was one of the first who attempted to enumerate the mineral elements of the soil necessary for plant growth. He made the important statement that no matter how favorable all other factors of growth might be, too great a deficiency or too great an excess of any single constituent necessary for the growth of crops would cause the soil to be unproductive (*380, pp. 303–304*). This was the first

definite announcement of the so-called law of the minimum, afterwards wrongly attributed to Liebig, who amplified Sprengel's statement by making the obvious conclusion that while all necessary elements are theoretically of equal value to the growth of the crop, the farmer must focus his attention upon supplying the particular deficient or absent element which then acquires practically a superior value (*218, pp. 25–26*). The deficiency of one nutrient element in the soil was held by Liebig to retard the assimilation of other nutrient elements below the limits obtainable under conditions of most favorable growth.

It was shown, however, by subsequent investigators that the absorption of increasing amounts of nutrient elements by the crop does not proceed in simple proportions, as assumed by Liebig, but that the operation of the law of diminishing

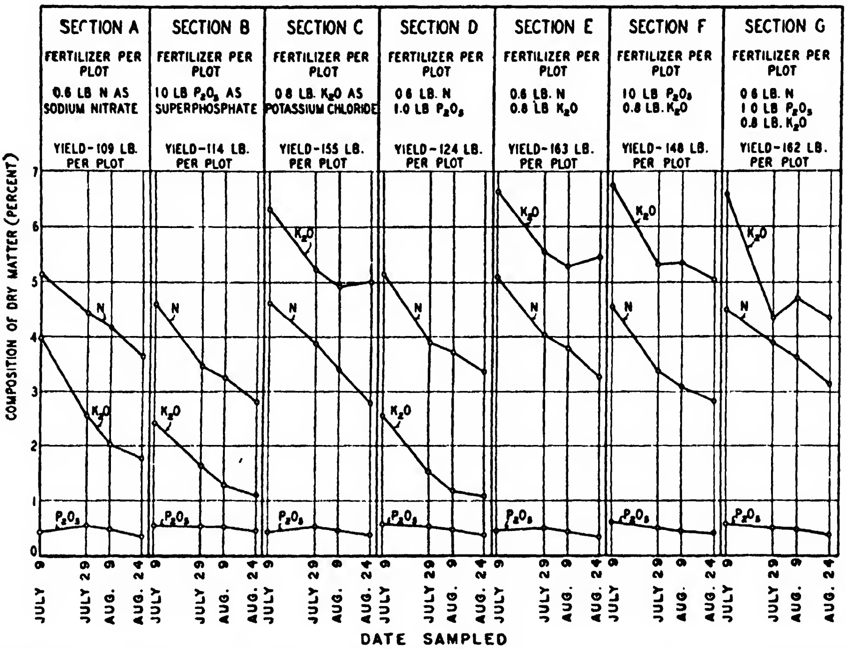

FIGURE 2.—Influence of different fertilizer treatments on the nitrogen, phosphoric acid, and potash content of potato leaves at different stages of growth.

returns brings absorption of nutrient and yield of crop to a final maximum beyond which further applications of fertilizer are not only ineffective but may be injurious.

Mitscherlich (*267*), by preparing soils that contained all essential nutrients, except the one to be studied, in sufficient amounts, and then supplying the missing nutrient in gradually increasing quantities up to the maximum of production, obtained for each of the nutrient elements growth curves of different crops that added greatly to knowledge of the subject. Mitscherlich found, however, that if too great an addition of one nutrient was combined with too great a deficiency of another a condition of unbalance was produced that led to a decrease instead of an increase in yield.

Later exceptions to the doctrine that increase of one nutritive element causes an increased assimilation of other nutrients were made by Lagatu and Maume (*209*) of Montpellier, France, who correlated their studies on fertilizer action with analyses of the leaves of crops from plots that had been treated with complete and with incomplete or unbalanced fertilizers and from check plots to which no fertilizer had been applied. With the soils peculiar to their experiments the results showed that an excess of some nutrients may diminish the absorption of a deficient element below the amount of the latter taken up by the plant from the same soil to which no fertilizer had been added. While the analysis of selected

leaves does not indicate the amount or distribution of the total nutritive ingredients absorbed by the whole crop, the foliar diagnostic method of Lagatu and Maume supplies a valuable index of the process of assimilation. An abstract of one of their experiments is given in table 19.

The two unbalanced fertilizers which lacked either potash or phosphoric acid gave yields of grapes that were much lower than that obtained from the vines to which no fertilizer at all was applied. With the advance of the season there was a marked decline in the content of nitrogen, potash, and phosphoric acid in the dry matter of the leaves for all the plots. Comparisons of results of treatments 2 and 3 for all periods show that unbalancing the fertilizer by withdrawal of phosphoric acid caused a reduction of the phosphoric acid content of the leaves below that of the leaves from the vines which received no fertilizer. Similar comparisons of results of treatments 2 and 4 show that withdrawal of potash caused a reduction of the potash in the leaves below that of the leaves from vines which received no fertilizer. The general effect of the increase of one nutrient was to cause a decrease in the leaf content of the other two nutrients, and this appears to be contrary to the assumption of Liebig that an increase of one nutrient causes an increased assimilation of other nutritive elements.

By applying the foliar diagnostic method of Lagatu and Maume to potato leaves at four different periods of growth, Thomas (*400*) obtained results at State College, Pa., which are indicated graphically in figure 2.

Figure 2 indicates that with minor exceptions the percentages of nitrogen, potash, and phosphoric acid in the dried potato leaves decrease with increasing age of the plant. The percentages of nitrogen, potash, and phosphoric acid are also higher throughout the whole period in the dried foliage of plants to which each of these respective nutrients had been supplied. This increase is especially noticeable in the case of potash. As in the experiments of Lagatu and Maume the general effect of the addition of one nutrient was to cause a decrease in the leaf content of the other two nutrients.

USE OF FERTILIZERS TO INCREASE THE MINERAL CONTENT OF CROPS

While it is possible to increase to a certain extent the content of valuable mineral constituents of some crops by special intensive methods of fertilization, a warning should be sounded against any exaggerated and sensational claims for mineralizing human and animal foods. From the preceding discussion it is evident that the mineral content of crops can be modified within certain limits in numerous ways. Different varieties of wheat, potatoes, peas, beans, cabbage, etc., vary in their capacity for assimilating potassium, calcium, magnesium, phosphorus, and other mineral elements from the soil. Certain strains of plants might therefore be cultivated to produce more of a given mineral nutrient which would perhaps be advantageous for specific purposes provided there was not a corresponding loss of some other valuable constituent. There are, however, so many factors, such as differences in soil, cultivation, altitude, rainfall, temperature, sunshine, etc., which influence the yield and composition of crops that a mineralization formula producing favorable effects in one region might prove to be detrimental in another locality. Thus Borden in the case of POJ 2878 sugarcane grown upon the same soils at Makiki and Manoa, Hawaii (*40, p. 156*), found that the quality of the cane grown under the unfavorable climatic conditions of Manoa was adversely affected by heavy applications of fertilizer, whereas similar applications had no injurious effect upon the cane grown under the more favorable climatic conditions of increased sunshine and diminished rainfall at Makiki.

The manner in which the content of mineral nutrients in crops can be modified by increased applications of fertilizers is well shown in some recent experiments by Opitz, Rothsack, and Morgenroth (*289*) of Germany, of which a graphic summary is shown in figure 3. Summer barley was grown in Mitscherlich pots containing a sandy soil (Bornimer Boden) deficient in nutrients, to which a basic supply of 1 g of nitrogen as ammonium nitrate had been supplied per pot. Increments of 0, 0.5, 1, and 2 g of potash as potassium sulphate were then supplied to four series of pots, the four members of each series having received respectively 0, 0.5, 1, and 2 g of phosphoric acid as dicalcium phosphate. The yield of dry straw and grain and the percentages of nitrogen, phosphoric acid, and potash contained therein were determined for each pot of soil. The results for percentages of total dry matter of crop (straw and grain) are plotted graphically in figure 3.

The results of this experiment indicate percentages of nutrients in the dry matter of the total crop and not in the dry matter of a few selected leaves, as in the experiments of Lagatu and Maume (*209*) and of Thomas (*400*). They offer, therefore, a better means of testing the validity of Liebig's hypothesis that increased assimilation of one nutrient causes an increased assimilation of other nutrients.

In section A of figure 3, where no phosphoric acid was used, increasing applications of potash increased greatly the percentage of potash and also very perceptibly the percentage of phosphoric acid in the dry matter of the crop. The

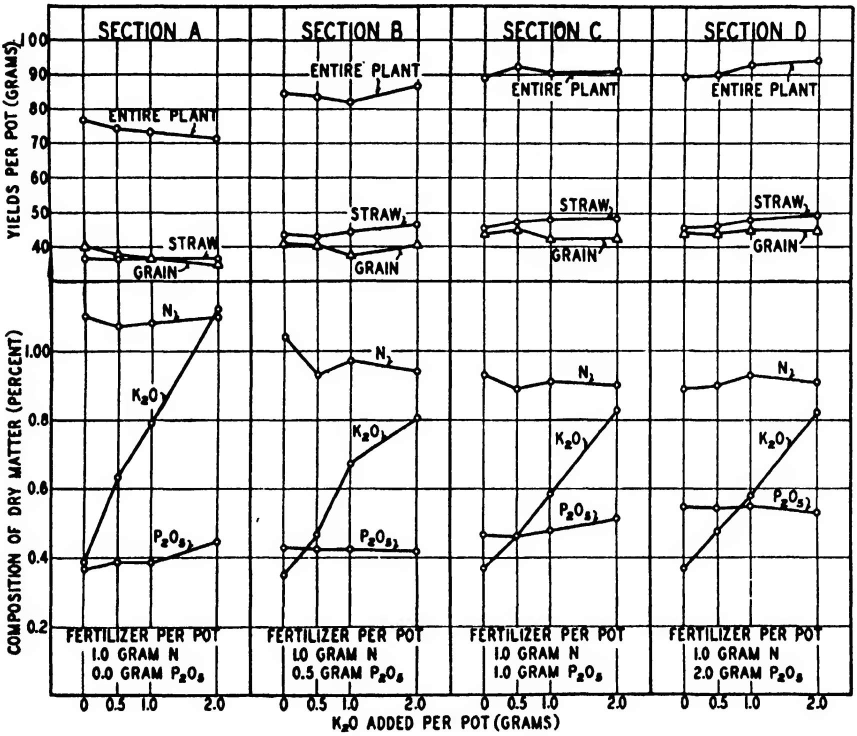

FIGURE 3.—Influence of different fertilizer treatments on nitrogen, phosphoric acid, and potash content of summer barley, entire plant, and on the yield of straw and grain.

same increase is also very noticeable in section C of the diagram. The percentage of nitrogen was reduced with the first application of potash but with the second application it underwent a perceptible increase, the same effect being indicated also in other sections of the figure. The immediate effect of the first additions of potash in sections A and B was to lower the yield of crop, the decrease being most noticeable in the case of the grain. The injurious effect of the unbalanced state of the nutrients in these cases of phosphoric acid deficiency is thus very plainly intensified by the addition of potash. The effect is similar to that indicated in the experiment of Lagatu and Maume (table 19) in which applications of unbalanced fertilizers produced yields of crop inferior to those obtained upon an unfertilized plot.

Increasing additions of phosphoric acid produced changes of a very different character (fig. 3). The total phosphoric acid content of the crop was raised, as one would expect. The first addition of phosphoric acid produced a very marked decrease in both the nitrogen and potash percentages of the crop (sections A and B). These decreases, however, reach a constant level and no perceptible diminutions

of nitrogen and potash are noticeable in sections C and D. The yield of crop increased with each addition of phosphoric acid, but the curve flattens out, the increment being least with the final greatest application. The results obtained by analyzing the mineral matter of the whole crop confirm in general the findings based upon the analysis of selected leaves according to the method of Lagatu and Maume (*209*).

According to the observations of this experiment the hypothesis of Liebig (*218*) that an increased application of a deficient nutrient will elevate the assimilation of other nutrients is only partially verified in the case of potash applications and definitely disproved in the case of phosphoric acid applications. The diagram shows that the mineral composition of crops can be affected only within certain limits. An increase of one constituent is offset by the decrease of another. Two great an excess, as well as too great a deficiency, of a particular nutritive element brings with it an injury to the crop which is reflected in lowered vitality and diminished yield. Somewhere between the limits of excess and deficiency for the different essential elements—nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, etc.—is the optimum range of the well-balanced or harmonious mixture of nutrients which will be found to vary according to the nature of soil, variety of crop, supply of water, amount of sunshine, and numerous other environmental conditions.

SOME RELATIONSHIPS OF SOIL DEFICIENCIES OF MAJOR ELEMENTS TO NUTRITION

To Plant Nutrition

It was realized by investigators in the United States more than a century ago that a chemical analysis, while informative as to the relative amounts of mineral nutrients present in a soil, does not supply information as to the availability of these nutrients to the plant. Field tests in which plots of various crops were subjected to different fertilizer applications were then introduced as a means of diagnosing the needs of soils for particular nutrients. Such tests, however, were time-consuming and expensive, and investigators therefore directed their attention to the search for more rapid methods.

Chemical analysis of the ash of rye seedlings grown upon the soils under investigation was proposed by Neubauer (*277*) as a rapid means of diagnosis, and this method has found considerable favor. Lagatu and Maume (*209*) have proposed the analysis of the ash of carefully selected leaves of the particular crop as another method of diagnosis (diagnostique foliaire). The practical applicability of their method to wide ranges of crops and soils remains, however, to be demonstrated.

Another method of foliary diagnosis relates to the perception of distinguishing abnormalities in the color, formation, and other visible characteristics of the leaves of crops. This line of research has been developed especially upon sugar beets by Krüger (*202*) at Bernburg in Germany, upon fruit trees by Wallace (*448*) at Long Ashton in England, upon tobacco by McMurtrey (*232*) of the United States Department of Agriculture, and upon sugarcane by Martin (*245*) in Honolulu. The abnormalities due to mineral deficiencies or excesses must be carefully distinguished, however, from abnormalities resulting from fungus diseases, insect damage, drought, and other causes; otherwise errors may occur through misinterpreting the observations. Because of the varying behavior of different plants the student must familiarize himself with the diagnostic criteria of mineral deficiencies for each particular crop. As a general rule the leaf abnormalities resulting from the absence of a particular element in the soil are greatly accentuated when the other nutrient elements are present in excess. A few diagnostic appearances noted by McMurtrey (*232*) in the case of tobacco are given herewith.

Abnormalities of growth due to mineral deficiencies or excesses are placed by Krüger in the class of "nonparasitic" diseases, to which belong also the diseases induced by unfavorable soil reactions. Sand drown (*120*), a chlorosis of tobacco due to magnesium deficiency (as demonstrated by the work of Garner, McMurtrey, Bacon, and Moss), is another example of nonparasitic disease. It should be remarked, however, that mineral deficiencies may so weaken the vitality of the plant that it becomes much more susceptible to the attacks of parasitic, as well as of nonparasitic, diseases. Thus the ravages of the parasitic pythium root rot disease of the sugarcane in Hawaii have been successfully counteracted by the application of mineral fertilizers.

Key to deficiency effects on tobacco plants grown in solution cultures[3]

Decreased growth; more or less localized effects; causal parasites absent.	*Group 1.*—Effects general on whole plant or localized on older or lower leaves of plant.	General, on whole plant; also yellowing and drying up or firing of lower leaves.	Nitrogen	Plant light green. Lower leaves yellow and dry to a light-brown color. Stalk slender and short. Roots long, with few lateral branches, white in color.
			Phosphorus	Plant dark green. Lower leaves may yellow and dry to a greenish-brown to black color. Stalk slender and short. Roots long with few lateral branches, reddish-brown color.
		Local, occurring as mottling or chlorosis, with or without necrotic spotting of lower leaves; little or no drying up of lower leaves.	Potassium	Lower leaves mottled with necrotic spots at tips and margins, which are tucked or cupped under. Stalk slender, necrotic areas in extreme cases. Roots long, with few lateral branches and of a yellowish, slimy appearance.
			Magnesium	Lower leaves chlorotic and typically show no spots. Tips and margins turned or cupped upward. Stalk slender, necrotic areas in extreme cases. Roots long, with few lateral branches and slimy in appearance.
	Group 2.—Effects localized on newer or bud leaves of plant.	Terminal bud remains alive, chlorosis of newer or bud leaves, with or without necrotic spots; veins light or dark green.	Iron	Young leaves chlorotic, typically show no spots. Principal veins typically green. Stalk slender and short. Roots short, with abundant short laterals, brown in color.
			Manganese	Young leaves chlorotic, with necrotic spots scattered over leaf. Smallest veins tend to remain green, producing a checkered effect on leaf. Stalk slender. Roots not abundant; brownish in color.
			Sulphur	Young leaves light green; no necrotic spots. Veins lighter green than intervein tissue. Stalk short and slender. Roots white, abundant, and much branched.
		Death of terminal bud, which is preceded by peculiar distortions at the tips or base of young leaves making up bud.	Calcium	Young leaves making up terminal bud first typically hooked, then die back at tips and margins so that later growth of such leaves shows a cut-out appearance at tips and margins. Stalk finally dies back at terminal bud. Roots short, much branched, dark brown in color, more or less decomposed.
			Boron	Young leaves making up terminal bud first light green at base, then more or less break-down takes place at base of young leaf, and if later growth follows, leaf shows twisted growth. Stalk finally dies back at terminal bud. Roots have many short laterals, brown color, and somewhat decomposed.

[3] Symptoms under these conditions are similar to those observed in the field on the tobacco plant, except for iron and manganese deficiency, which have not been seen on tobacco in the field.

To Animal Nutrition

One of the first definite expressions of the close relationship of soils to animal nutrition was made by Sprengel (*380, p. 46*) in the following significant passage: "Red clover for example which has grown upon a marly soil, always contains more calcium, phosphorus and sulphur than red clover which has grown upon a loamy soil since the latter as a rule does not make available to red clover as much calcium, phosphorus and sulphur as the marly soil. If we consider next that calcium, phosphorus and sulphur are most essential for the growth of the animal body, it is perfectly evident, as repeated experiments on a large scale have proved, why clover from a marly soil is more nutritious than clover from a loamy soil."

The earliest convincing reference in the American literature to the intimate chemical relationship of soils of definite geological origin to the composition and nutritive value of the crops grown thereon is contained in the second report of the Geological Survey of Kentucky (1857) by David Dale Owen (*292*). He called attention to the luxuriant growth of bluegrass on soils derived from the blue limestone and marls of the lower Silurian period in Kentucky and to the remarkable development of the stock pastured on the fields of this region. Such stock, he remarked, is—

"For the most part . . . almost a year in advance in bulk, weight, and form, to the stock raised on the soils derived from the Carboniferous group.

"The acknowledged superiority of this soil is evidently due to the preponderance of the mineral constituents, lime, phosphoric acid and the alkalies. It contains, as will be seen, fourteen times as much lime, three times as much phosphoric acid, and more than twice as much potash as soil from the Coal Measures" (*292, p. 30*).

The difference in composition of these soils is indicated in table 20, from analyses by Peter (*298, pp. 255, 281*).

Table 20.—*Comparison of composition of virgin soil in two different localities in Kentucky*

Component	Lower Silurian, Woodford County	Coal Measures, Ohio County	Component	Lower Silurian, Woodford County	Coal Measures, Ohio County
	Percent	*Percent*		*Percent*	*Percent*
Organic and volatile	7.771	5.080	Sulphuric acid	0.170	0.413
Oxides of aluminum, iron, and manganese	12.961	4.349	Potash	.393	.157
			Soda	.130	.015
Carbonate of lime	2.464	.176	Sand and insoluble silicates	75.266	90.166
Magnesia	.173	.166			
Phosphoric acid	.319	.101			

A second relationship of soil composition to animal nutrition disturbances, repeatedly mentioned by Owen, concerned the much disputed question of the possible injurious effect of certain magnesian soils on plant and animal growth. Owen observed that a disease known as milk sickness, or trembles, of cattle seemed to be most prevalent in regions where the soils were derived from a silicious mudstone or shale of relatively high magnesia content. Several analyses of such shales as recorded by Peter (*298, p. 164: 299, p. 254*) are given in table 21.

The samples from Scott County were from districts where milk sickness was very prevalent. Owen (*292, p. 73*) supposed that astringent salts such as magnesium sulphate, produced by the decomposition of these shales, were possibly assimilated by grass, the ingestion of which by the animals might produce the illness. It has been lately shown, however, by Couch (77) of the Department of Agriculture, that milk sickness, for over a century the puzzle of agricultural scientists, is produced by a toxic organic constituent (tremetol) of certain plants, such as white snakeroot (*Eupatorium urticaefolium*) and jimmyweed (*Aplopappus heterophyllus*), upon which the animals had fed. Whether such plants have a peculiar preference for certain types of magnesian soils is a phase of the question which has not been investigated.

Table 21.—*Comparative analyses of silicious shales and mudstone in Fayette and Scott Counties*

Component	Fayette County shale	Scott County shale	Scott County mud-stone	Component	Fayette County shale	Scott County shale	Scott County mud-stone
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
Sand and insoluble silicates	83.45	75.920	77.840	Carbonate of magnesia	2.30	6.220	3.401
Oxides of aluminum, iron and manganese	10.25	11.660	9.140	Phosphoric acid	.50	.482	.566
Carbonate of lime	1.79	1.480	3.784	Sulphuric acid	.92	.338	.303
				Potash	.41		.579
				Soda	.01		.047

Since there is ordinarily a sufficient abundance of potassium and magnesium in most plant products used as food by men and livestock, dietitians and cattle feeders limit their attention chiefly to calcium and phosphorus, so far as the major mineral nutritional elements essential to animal nutrition are concerned.

An unpublished compilation of the chemical analyses of 389 topsoils and 350 subsoils, prepared by the late Milton Whitney, gives the average percentage distribution of the major components (table 22).

Table 22.—*Average composition of topsoils and subsoils*

Component	Topsoil	Subsoil	Component	Topsoil	Subsoil
	Percent	*Percent*		*Percent*	*Percent*
Silica	74.90	70.11	Potash	1.55	1.55
Alumina	9.57	12.86	Sodium oxide	.85	.84
Iron oxide	3.75	5.13	Phosphoric acid	.15	.15
Lime	1.56	1.93	Loss on ignition	5.92	5.61
Magnesia	.84	.95			

Of the eight major soil components listed phosphoric acid is by far the least abundant. A deficiency of calcium, the most abundant mineral element in the animal body, is often associated with a lack of phosphorus in the soil; the importance of having an abundant supply of these two elements in soils is at once apparent when we consider that 95 percent of the inorganic bone material of animals is composed of calcium phosphate.

One of the best illustrations of the close relationship of soil deficiencies to animal diseases is afforded by the outbreak of certain maladies, such as softening of the bones (osteomalacia) and depraved appetite for bones (osteophagia), among animals which graze upon the grasses of phosphorus-deficient soils. Such cases have long been recognized in various regions of the United States.

That deficiencies of calcium and phosphorus in grain and hay were the primary cause of bone softening, bone eating, and other related diseases of cattle had been recognized as early as 1861 in Germany by Von Gohren (*125*), who referred to serious outbreaks of this nature in certain regions of Hesse along the Rhine in the year 1859. The sheep and cattle ate with avidity the bonemeal which had been used as a fertilizer. In addition to a natural deficiency of phosphates, Von Gohren suggested a possible loss of mineral matter from the forage as a result of the leaching action of rain. That such losses from leaching do occur, especially in the case of dried grass and hay, has been demonstrated by the later work of LeClerc and Breazele (*214*). Von Gohren showed that osteomalacia of cattle could be prevented and cured by supplementing the rations with bonemeal, which his experiments proved to be well assimilated by the animals. He suggested that unfavorable effects of bonemeal feeding might be due to the use of too great an excess or to the presence of putrefactive products.

Without further citation of the immense amount of literature upon this subject that appeared in the agricultural journals of European countries in the latter part of the previous century, a few references will be made to more recent investigations upon the relationship of osteomalacial diseases to phosphorus deficiency of the soil.

At the meeting of the American Veterinary Medical Association at St. Louis in August 1904, J. M. Parker (*294*) called attention to the occurrence of creeps, an osteomalacial disease of cattle, in certain parts of Texas, but no light was thrown upon the cause of the disease. Cases of bone eating among cattle were reported in Montana as early as 1910 but it was only when the better lands were withdrawn for farming and grazing became more and more limited to poorer soils that the situation became acute. At the meeting of the American Veterinary Medical Association at New Orleans in November 1919, reference was made by C. A. Cary (*62a*) to the occurrence in the Coastal Plain of south Alabama of a cattle disease called sweeney or creeping sickness, in which the animals showed emaciation and leg weakness and developed a depraved appetite for bones. This type of osteomalacia was attributed to a possible deficiency of lime and phosphoric acid in the native wire grass of the pastures, which in late summer becomes very tough and indigestible. In this earlier work in the United States no analytical correlations were established, however, between the chemical composition of the soil and the deficiency of lime and phosphoric acid in the pasture grasses upon which the animals fed.

Meanwhile in the Union of South Africa, Sir Arnold Theiler, director of veterinary research, and his associates were investigating certain cattle diseases, known locally as lamsiekte and styfsiekte, which for a long time had afflicted cattle that grazed upon certain areas of the South African veld. Theiler at first attributed lamsiekte to a cumulative vegetable poison or toxin in the pasture grass, but his later investigations, supported by chemical analyses of soils and forage, proved the disease to result primarily from a deficiency of phosphorus in the grasses of the affected areas. This first demonstration by chemical analysis of the relationship of osteomalacial diseases of cattle to phosphorus deficiency in the soil was made by Theiler, Green, and Dutoit in an article (*397*) published in 1924, from which table 23 is taken.

Table 23.—*Composition of South African soils associated with lamsiekte and styfsiekte diseases of cattle*

Mineral constituent	Lamsiekte soils, Armoedsvlakte, Vryburg		Styfsiekte soils	
	Dolomitic areas (1)	Leached areas (2)	Lidgetton, Natal heavy loam (3)	Athole, Ermelo medium gray loam (4)
	Percent	*Percent*	*Percent*	*Percent*
Lime	12.07	0.16	0.08	0.05
Magnesia	21.34	.12	.43	.05
Total potash	.11	42	.73	.03
Total phosphoric acid	.12	.03	.09	.06
Available potash	.016	.011	.02	.004
Available phosphoric acid	.001	.0005	.001	.001

All soils show a marked deficiency in available phosphoric acid and potash, and soils (2), (3), and (4) a strong deficiency in lime. These deficiencies are reflected also in the mineral composition of the mixed grasses, as is seen from the proximate analyses in table 24 of the dry matter of the Armoedsvlakte mixed grasses (*397*).

The young grass of early spring (October and November) is very nutritious and except for a deficiency in lime approximates the composition of European rich pasture grass, but in March and April, after the formation of the seed, the feeding value rapidly diminishes and thereafter is much inferior to poor quality European meadow hay. The most striking feature of this comparison is the extraordinarily low phosphorus content of the old grass, which is only about one-fifth that of poor European hay. The percentage of lime in the Armoedsvlakte grass is also abnormally low. As a result of these marked deficiencies of the grass in phosphoric acid and lime, the intake by cattle of these bone-forming constituents is far below the level of maintenance. Animals living on such grass develop a depraved

craving for bones (osteophagia), and if the latter are contaminated with putrefying flesh or other tissue an infection with bacterial toxins brings on the disease of lamsiekte, which has caused great losses of cattle in the South African veld.

Table 24.—*Seasonal composition of mixed grasses grown on South African soils deficient in phosphorus and calcium*

Date and feed	Crude protein	Ether extract	Nitrogen-free extract	Crude fiber	Ash	Phosphoric acid	Lime
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nov. 10, 1919	19.4	5.5	41.0	22.5	11.6	0.60	0.31
Dec. 8, 1919	14.3	5.6	46.8	25.6	7.7	.32	.59
Jan. 15, 1920	13.8	5.5	48.0	25.0	7.7	.22	.50
Mar. 4, 1920	7.2	3.4	49.8	33.7	5.9	.24	.43
Apr. 19, 1920	4.9	2.4	51.6	35.0	6.1	.11	.46
May 11, 1920	4.1	2.2	52.9	34.9	5.9	.07	.50
June 8, 1920	4.0	2.0	53.7	33.1	7.2	.09	.59
European rich pasture grass	20.5	4.6	45.9	19.0	10.0	.7	.9
European poor meadow hay	8.7	1.7	44.8	39.0	5.8	.4	.9

The disease known as styfsiekte, which is not related to bacterial infection, appears to result either from phosphorus deficiency or from a deficiency of both calcium and phosphorus. In either type of disease the feeding of bonemeal to the animals brings speedy recovery with complete disappearance of osteophagia, which is a characteristic symptom of phosphorus deficiency in the diet. Even where osteophagia is lacking, the intake of phosphorus and calcium by the animal may be below the level of maintenance, with a consequent decline in vigor and growth. The feeding of bonemeal in South Africa has been found not only to eliminate the aggravated symptoms of lamsiekte and styfsiekte but to produce "increase of milk yield in cows, better calves at birth, more rapid growth of young stock and superior fattening of adult cattle."

Outbreaks of osteomalacia and bone eating among cattle have been reported in the United States since 1910 in Montana, Minnesota, Wisconsin, Michigan, Texas, Alabama, Florida, and very recently in Tennessee. In most of the affected regions the cases are confined to localities where the cattle subsist largely or entirely upon the grass of phosphorus-deficient soils. Such grass in its later period of growth, and especially in times of deficient rainfall, is very low in phosphoric acid.

The decline in phosphorus content of bur-clover (*Medicago hispida*), alfilaria (*Erodium* sp.) and other range grasses during their period of growth has been studied by Hart, Guilbert, and Goss (*149*) of the California Agricultural Experiment Station. The seasonal trend of protein and phosphorus in mixed forage consisting of bur-clover, alfilaria, and grass range and of alfilaria and grass range is shown in figure 4, which represents the average of many analyses made by these investigators.

Figure 4 explains clearly "why a range containing bur clover holds its carrying capacity for livestock better than one in which this forage plant is absent." The downward trend and low percentage of phosphorus in alfilaria and grass range during summer and autumn are characteristics similar to those noted by Theiler and his associates (*397*) for the phosphorus-deficient grasses of the South African veld. Hart, Guilbert, and Goss note that the samples "in which the phosphorus was above the average came, in general, from the heavier soils and best grazing areas. Those that plotted below the average were from land recognized as poorer grazing areas."

The relation of phosphorus content of the soil to that of the forage grown thereon and to phosphorus deficiency in cattle has been very thoroughly investigated by Eckles, Gullickson, and Palmer (*100*) in their studies of conditions in various sections of Minnesota. The correlations of bone weakness, bone chewing, etc., of cattle with low phosphorus content of their blood plasma, with low phosphorus content of the forage upon which the animals fed, and with low phosphorus content of the soils upon which the forage crops were grown are demonstrated with unmistakable clearness.

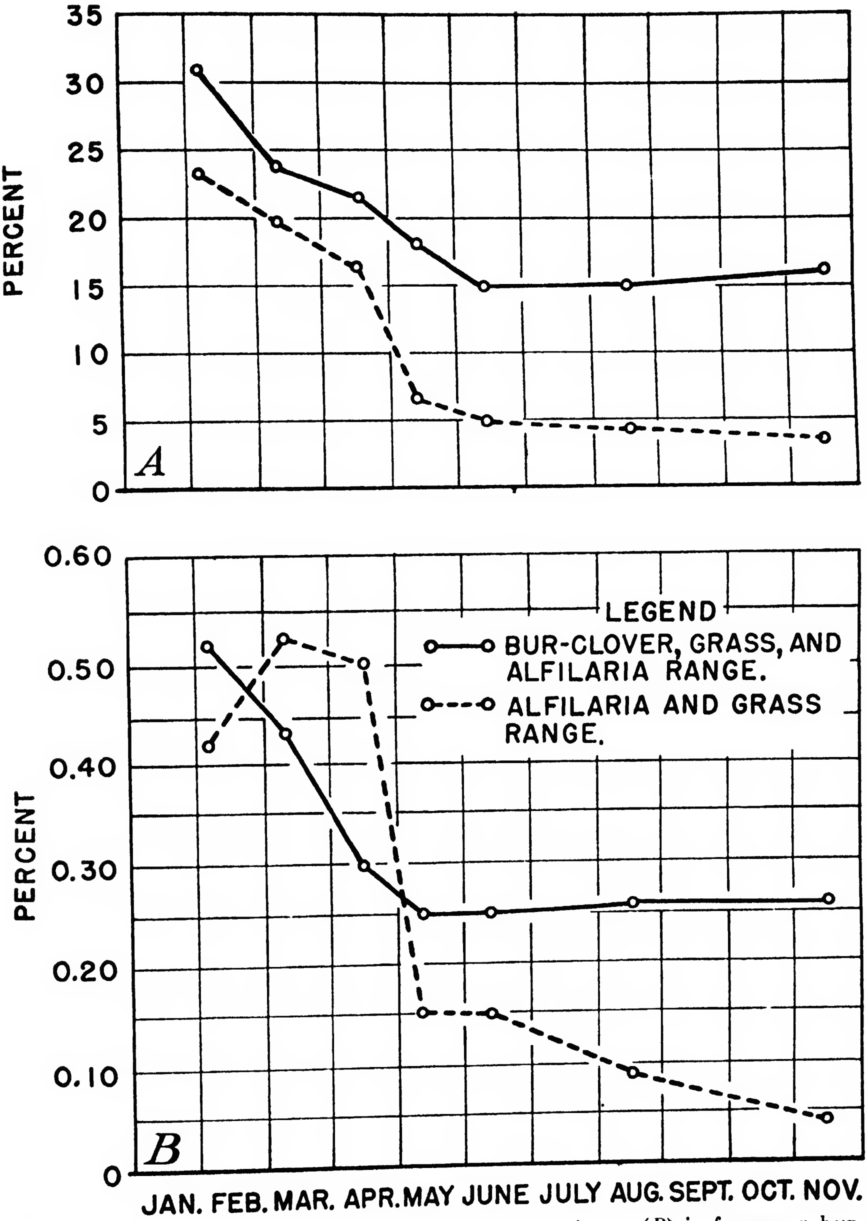

FIGURE 4.—Seasonal trend of protein (*A*) and phosphorus (*B*) in forage on bur-clover, alfilaria, and grass range, compared with an alfilaria and grass range.

From their studies with inorganic phosphorus supplements, Eckles, Gullickson, and Palmer (*100*), conclude that livestock growers are wholly justified in their practice of supplying cattle in regions of phosphorus-deficient soils with mineral phosphates, although they fully recognize the additional benefits that animals obtain from the protein, fat, etc., of feeds that are rich in natural forms of phosphorus.

A comparison of the calcium, phosphorus, and magnesium contents of prairie hay, timothy hay, and alfalfa hay from the low phosphorus soils of Minnesota is shown in table 25 (*100, p. 47*). The average values given by Henry and Morrison (*271*) are added for comparison.

Table 25.—*Composition of hay grown on phosphorus-deficient soils of Minnesota*

Crop and source of analyses	Samples	Calcium	Phosphorus	Magnesium
	Number	*Percent*	*Percent*	*Percent*
Prairie hay:				
Low phosphorus area of Minnesota	51	0.440	0.106	0.233
Nygarrd farm, 7 years	24	.410	.064	.258
Timothy hay:				
Low phosphorus area of Minnesota	5	.395	.112	.197
Henry and Morrison average		.179	.135	.102
Alfalfa hay:				
Low phosphorus area of Minnesota	24	1.810	.212	.397
Henry and Morrison average		1.390	.235	.456

The phosphorus content of the prairie hay is only half of that in the alfalfa hay, which explains the fact that but little phosphorus-deficiency trouble occurs among animals when alfalfa hay is fed. The prairie hay from the Nygaard farm represents an extreme case of phosphorus deficiency.

Climatic factors were found by Eckles, Gullickson, and Palmer to have a strong influence upon the mineral content of hays from low phosphorus soils. This is indicated in table 26, which gives the composition of alfalfa, timothy, and prairie hays for 2 successive years of different rainfall (*100, p. 49*).

Table 26.—*Mineral content of hays from low-phosphorus soil as affected by rainfall*

Variety of hay	Annual rainfall	Samples	Mineral content: Calcium (Ca)	Mineral content: Phosphorus (P)	Mineral content: Magnesium (Mg)
	Inches	*Number*	*Percent*	*Percent*	*Percent*
Alfalfa	17.49	4	1.903	0.132	0.469
	21.98	10	1.891	.212	.411
Timothy	17.49	2	.465	.096	.238
	21.98	2	.322	.118	.151
Prairie	17.49	12	.379	.067	.188
	21.98	18	.437	.123	.231

The much lower phosphorus content of the hays in the year of lower rainfall explains why the effects of phosphorus deficiency are more pronounced in seasons of drought.

Evidences of phosphorus deficiency in forage manifest themselves not only in the more striking symptoms of bone weakness and depraved appetite, but also in diminished growth, lessened production of milk, and lowered capacity of reproduction. The extra demands of the animal for phosphorus and other mineral constituents during the periods of gestation and lactation necessitate a higher content of these elements in the ration than for ordinary conditions of maintenance.

Of all soil constituents, phosphorus is the one about which the agronomists of different countries express the greatest fear of ultimate exhaustion. It is the major essential component whose deficiency in the soil is linked with the greatest number of disturbances in the health of animals and the element which offers the most striking and convincing demonstrations of the close relationship between the chemical composition of the soil and the health and vigor of the plants and animals that live upon it.

In addition to the States previously named, where the phosphorus-deficiency problem is regionally acute, there are many other States, including California, Colorado, the Dakotas, Nevada, New Mexico, Utah, and Washington, where evidences indicate that similar troubles may arise locally.

***ONE BY ONE,** new elements have been added to the list of those known to be necessary for plant growth and health. Some of these elements are needed in only a few parts per million of soil; yet without this trace, plants—and animals also—suffer from serious diseases. This is one of the most interesting fields of modern research in plant and animal nutrition. It is dealt with in this article, which closes with a reference list of so-called secondary elements and what is known about each of them in relation to the health of plants and animals.*

Neglected Soil Constituents That Affect Plant and Animal Development

By J. E. McMurtrey, Jr., *and* W. O. Robinson [1]

BECAUSE of its complex nature, the soil commonly contains small quantities of numerous chemical elements certain of which, in suitable compounds, are necessary in small amounts for plant and animal development. Frequently, however, elements that are essential at low concentration become toxic if they are available in slightly higher concentrations. Unusual soil constituents frequently occur naturally, or they may be added by man accidentally—and sometimes intentionally in controlling insects, rodents, weeds, or plant diseases—in amounts that are deleterious to plant development and to the animals feeding upon the plants.

The response of the plant or animal to a deficiency or excess of an element in the diet can most accurately be recognized and measured by the symptoms produced. The actual quantities involved are frequently so minute that routine chemical procedures are not sufficiently delicate to measure amounts that produce striking effects on the plant or animal organism. Recent careful study of the effects of these elements on growth has supplied the explanation of failures in plant and animal development previously attributed to unknown causes or, in some instances, erroneously to other conditions.

It is now generally admitted that for normal development plants require the following chemical elements in suitable compounds: Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, boron, copper, and zinc. Animals may require all of these and in addition sodium, chlorine,

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iodine, and cobalt. The quantities necessary for the normal development of plants or animals vary considerably. Those required in small quantities include iron, manganese, boron, copper, zinc, iodine, and cobalt. The members of this last group are the ones that commonly become toxic in slightly larger quantities than those required. Another group of elements that are toxic at relatively low concentrations includes aluminum, arsenic, barium, chromium, fluorine, lead, selenium, and thallium.

The elements present in plants and animals in very small quantities are commonly referred to as "rare," "trace," or "minor" elements. None of these terms is entirely suitable; most of the elements are in no sense rare, they do not occur in traces in all plants or soils, nor are the effects they produce on plant or animal development of a minor nature. There appears to be no completely satisfactory term that can be used to refer to this group of elements. The term "secondary elements" is used frequently in the following discussion to contrast this group with the primary group that includes nitrogen, phosphorus, potassium, and calcium. However, this use of the term is merely for convenience and is not to be construed to mean that they are of any less importance for normal plant and animal development.

The importance of the secondary elements to plant growth was not generally realized till early in the present century. The method used to demonstrate the necessity for them was to grow plants in media from which the elements under investigation were withheld. In such tests, however, the few parts per million of boron, zinc, manganese, etc., necessary for plant growth were frequently present as impurities in the water supplied, in the chemicals ordinarily used in preparing the nutrient solutions, in the sands, or in the containers. It was only by exercising the strictest chemical control in excluding traces of the elements under study that proof of the plants' requirements could be established.

Every few years a new chemical element has been added to the list of those that plant physiologists consider essential to plant growth. Early in the present century Gabriel Bertrand and coworkers announced that manganese, boron, and zinc are necessary for plant development. More than 20 years elapsed before this was generally accepted. A few years ago the same chemist announced that nickel and cobalt were present in all soils and plants, and that in plants these elements were concentrated in the leaves. He raised the question whether they are not really essential plant constitutents. Nickel and cobalt occur in plants in the order of only a few parts per million.

The quantities of many of the secondary elements in plants are equivalent to only a few pounds per acre. This in terms of the soil is but a few parts per million,[2] and since the soil is such a complex mixture of a great number of different minerals, many of which are of complex composition, it is only natural to suppose that the average soil would contain enough of the secondary elements to produce normal plant growth.

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[2] A general idea of the quantities of the secondary elements involved in plant growth is given by the following facts: An acre of soil to the depth of a foot weighs roughly 4,000,000 pounds. One pound of boron per acre has been recommended as a field application for tobacco. This is one-fourth part per million on the soil weight basis. If we assume an optimum moisture content of 20 percent and no absorption of boron by the soil, then there are 1¼ parts per million in the soil solution. Fifty pounds of nitrogen per acre often is a liberal application. This would result in a concentration of 62½ parts per million of nitrogen in the soil solution.

However, even before the agricultural workers of this country devoted much attention to the presence of the elements required in small amounts in relation to plant growth, they began to notice that in many places certain crops gave poor yields and were affected by what are now known as deficiency diseases. Familiar examples of these are the sand drown of tobacco, the magnesium deficiency disease of potatoes in the highly fertilized soils of Maine and in the sandy soils of the Coastal Plains, the chlorosis of tomatoes on certain Florida marl soils, pecan rosette, and citrus mottle leaf.

The sand drown of tobacco has been found to be due to a deficiency of magnesium. If the soil contains less than 0.2 percent of magnesium oxide (MgO) the tobacco plant is liable to suffer from sand drown. The chlorosis of tomatoes on certain Florida soils can be cured by the application of a few pounds per acre of manganese; in fact, a light application of stable manure furnishes enough manganese to remedy the chlorosis. Pecan rosette and citrus mottle leaf yield to the application of relatively infinitesimal quantities of zinc.

Yellows of tea has been corrected by use of sulphur compounds. It has recently been shown that internal cork of apples, top rot of tobacco, cracked stem of celery, internal browning of cauliflower, and heart rot and dry rot of sugar beets can be controlled by the use of small applications of boron to the soil on which these crops are grown. Copper compounds have produced remarkable results, especially on peat soils and in correcting the permanent wilting of the upper leaves of the tobacco plant caused by copper deficiency.

In some cases soil deficiencies are not revealed by any effect on plant growth yet the plant is not being supplied with a sufficient quantity of some elements to produce a normal healthy growth of animals feeding on it. Among examples of this is the failure of cattle to develop normally when feeding on the products of the sandy soils of Florida, which do not supply enough iron and copper, or possibly cobalt, to the plant. In New Zealand, the lack of enough cobalt in certain soils causes the "bush sickness" of sheep. The abnormal occurrence of human goiter in parts of Switzerland and of Wisconsin, Minnesota, and Washington is due primarily to a deficiency of iodine in the soil.

History furnishes one very pertinent example that appears to give a sound precedent in the application of elements that are not necessary for plant growth but the lack of which causes deficiency diseases in animals. Nearly all vegetative growth is so deficient in both chlorine and sodium that both these elements must be taken with the food to create the hydrochloric acid of the gastric juice and to counterbalance the large excess of potassium ingested with the plant. This problem was unconsciously solved by the physiological craving for salt, and the deficiency is easily made up by merely supplying salt to the animal. In some cases where a particular secondary element is not directly needed for plant growth, it appears that the soil deficiency might best be corrected in the same way.

Sometimes a certain element may be present in the soil in abundance, but because it is not in available form plants or animals may suffer from the lack of that element. The unavailability may be due to the insoluble nature of the soil minerals containing the element in question.

In other soils the reaction, acid or alkaline, may be such that the element is not sufficiently soluble in the soil solution. For instance, the liming of the soil to the neutral point and beyond may cause chlorosis due to lack of iron or manganese. A very small quantity of zinc in an acid soil may be sufficient to prevent pecan rosette, whereas in a neutral soil many times more would be quite ineffective.

Deficiencies of the secondary elements, except of iodine in special cases, are not likely to occur in soils formed from the decomposition of granite and other igneous rocks. These soils contain a great variety of minerals in the sands and silts, and also generally contain a relatively large amount of fine clay—the soil-absorption complex, which has the property of retaining many of the elements in a form not readily washed out by percolating water but still available to plants.

Many soils, such as the very sandy soils of the Coastal Plain, contain very little of the absorption complex, and the sands and silts contain very few minerals other than quartz. These soils are likely to show deficiencies of secondary elements necessary for the normal development of plants and animals. Soils of volcanic origin such as those of the Hawaiian Islands and New Zealand may show deficiencies in a number of elements. Soils high in calcium carbonate may produce deficiency diseases owing to the fact that boron, iron, manganese, and perhaps other elements are rendered relatively insoluble by that compound.

It is evident that in the future more attention must be paid to soil deficiencies of all elements essential for normal development of plants and animals. Larger crops grown on highly cultivated soils are exhausting the reserves in all cases where the crops are removed from the soil. There is also another potent factor operating in the same direction. The commercial fertilizers applied to obtain larger yields are for the most part comparatively pure salts, which through the phenomenon of base exchange tend to displace the secondary elements in the soil and cause them to be used by growing crops or carried away in the drainage water. These commercial fertilizers are different from farm manure in that they do not ordinarily contain enough of the secondary elements to be of any significance. It is not unreasonable to believe that some small part of the increased yield following the application of commercial fertilizers is due to the increased availability of the secondary elements rather than entirely to the nitrogen, phosphorus, and potassium applied.

There is a tendency at present to use very concentrated salts as fertilizers to reduce carriage and application costs. With the use of these concentrated fertilizers the depletion of the elements not supplied may be more rapid. Most pronounced in this direction will be the depletion of the sulphur, magnesium, and calcium reserves in the soil. Heretofore very little attention has been paid, in the fertilization of lands, to sulphur and magnesium. The reason for this is that potash salts and superphosphate, which are the principal constituents of most commercial fertilizers, frequently contain magnesia and commonly calcium with more sulphate than phosphate. Thus a deficiency of calcium, sulphur, and magnesium has not occurred as generally as would otherwise have been the case. American soils contain, on the whole, less sulphur than phosphorus, but if other sulphates such as

ammonium sulphate and potassium sulphate are used in the newer concentrated fertilizers, no sulphur deficiency should occur.

While the continuous use of chemical fertilizers tends to deplete the essential elements not supplied to the soil, the use of stable manure, leafmold, wood ashes, and peat tends to conserve them. On dairy farms, a large part of all elements is returned to the soil, and the secondary elements contained in such concentrates as are purchased from the outside are therefore actually added to it. Leaf litter, leafmold, and wood ashes contain many of the elements taken from the forest soil in proportions desirable for the nourishment of the trees. The undesirable ones have been largely eliminated. Furthermore, the secondary elements in leafmold, particularly manganese, are in a very available form. In long-continued experiments at Woburn and Rothamsted in England it has been found that stable manure has maintained the fertility of the soil over much longer periods than has the use of chemical fertilizers containing nitrogen, potash, phosphorus, and sulphur. The numerous chemical elements contained in the manure are undoubtedly an important factor in this observed maintenance of fertility.

Many of the elements naturally occurring in soils are as undesirable as some of them are necessary. Our present information leads us to believe that selenium, thallium, fluorine, chromium, lead, and probably arsenic, are undesirable soil constituents even at the lowest concentrations.

In some instances elements are added to the soil in the form of spray residue or by direct treatment as, for example, the relatively heavy applications of lead arsenate to the soil of nurseries for the control of the Japanese beetle. The addition of lead and arsenic appears to be unqualifiedly undesirable from the standpoints of the maintenance of soil fertility and of safeguarding animal health. Variations in soil composition and reaction cause great differences in the toxicity produced by these elements, which will be explained later under the descriptions of the effects of the two elements in question. Copper and sulphur are frequently added to the soil in the form of spray residues. The quantities of both these elements added per acre are comparatively small and except in extreme cases would be beneficial rather than harmful. The long-continued use of sulphur without liming would, however, cause a considerable rise in soil acidity and result in the depletion of the soil bases.

The problem of the addition of secondary elements to commercial fertilizer is a complicated one and must be conservatively handled. The compatability of carriers of secondary elements with other ingredients of the fertilizer mixture is to be considered. It will frequently be difficult to obtain a uniform mixture of the small amounts required. In many cases the chemical reaction of the clay or absorption complex, as well as the question of economy, will be a determining factor. Thus the addition of a pure manganese salt to a clay saturated with calcium will very soon result in the precipitation of insoluble manganese dioxide. A similar reversion to an insoluble form apparently occurs with zinc. Molybdenum and copper and other elements with similar properties have relatively insoluble sulphides. The presence of the sulphide ion in the soil may render these elements too insoluble to be of practical use.

Some of the secondary elements have very narrow ranges of concentration in which they are of use to plants. Boron is one of these. For many plants in water-solution cultures a few parts of boron per million are absolutely necessary for plant growth, while 20 or more parts per million are fatal to many plants. A familiar example of boron toxicity occurred during the World War when potash sources containing considerable borax were used in potato and tobacco fertilizers. In some cases as little as 30 pounds per acre resulted in greatly diminished yields, and applications in excess of 50 pounds killed the plants.

Although the search for unusual plant constituents is still in its infancy, it has developed that certain plants when grown in some environments concentrate one or another of these elements. Thus it has been found that the Australian silky oak, members of the *Symplocos* genus (sweetleaf), the clubmosses, and hickory are notable aluminum-absorbing plants. According to spectroscopic determinations some mushrooms have been found to contain 0.01 percent of silver. In the Danube region in Europe the scouring-rush (*Equisetum palustre*) is reported to be a "gold digger." A certain violet absorbs so much zinc it has been named *Viola calaminaria* from the zinc-bearing mineral calamine. The woody aster and various species of *Astragalus* take up so much selenium that a few ounces of the dry plant are a lethal dose for sheep. Other instances might be cited. As the study progresses, doubtless many other plants with voracious appetities for unusual elements will be discovered.

It has been reported, but is as yet uncomfirmed, that barium is concentrated in the eyeballs of animals, zinc in the reproductive glands, bromine in the pituitary body, and cobalt and nickel in the pancreas. The same authority reports that boron is concentrated in the pistils of flowering plants.

The lack of accurate information on the content of secondary elements in soils and plants and the effect of small quantities of these elements on animal and human health constitutes an important problem for further research.

A REFERENCE LIST OF THE SECONDARY ELEMENTS AND THEIR RELATION TO PLANT DEVELOPMENT

In the following pages the importance of individual chemical elements will be discussed from the viewpoint of their effects on plant and animal development. For convenience of reference they will be treated in alphabetical order.

Aluminum

Aluminum oxide, in combination with silica and water, forms the clay of the soil. Next to silicon it is the most abundant of the soil mineral constituents.

Aluminum in combination in the soil is the least soluble of the major soil elements and is one of the main constituents of lateritic soils,[3] which represent the end product of the soil-leaching processes. The solubility of aluminum in the soil is profoundly affected by the presence of other ions. Of these the hydrogen ion is of the most importance and the phosphate ion probably ranks next. Only the very acid soils have a sufficient concentration of hydrogen ions to dissolve

[3] See Formation of Soil, p. 948.

significant quantities of aluminum hydroxide, but the reactions occurring in the soil are not so simple as those studied in the laboratory, and in the presence of the complex forms of organic matter in the soil much alumina is probably held in solution at hydrogen-ion concentrations that would completely precipitate pure aluminum hydroxide.

There is some doubt as to whether aluminum is essential to plant growth. Plants vary greatly in alumina content. In general the greatest concentrations are found in the roots. In the leaves the element is generally present as a few hundredths of 1 percent of the dry weight, and will average somewhat higher than iron. Like iron, zinc, and manganese, aluminum in the leaves follows the concentration of the chlorophyll, being much greater in green than in blanched or chlorotic leaves.

Some plants appear to be specifically aluminum-loving. A sample of sweetleaf (*Symplocos tinctoria*) contained 4.54 percent of alumina. Hickory and tea leaves growing on acid soils contain nearly 2 percent, and on limestone soils that are alkaline in reaction hickory leaves have been found to contain 0.25 percent. Parts of other plants, such as barley hulls and barley grains, contain as much as 0.5 percent.

Plants growing on acid soils have more alumina than the same kind of plant on neutral or alkaline soils. In fact, the toxicity of very acid soils has been ascribed to the soluble or active aluminum present. The element is toxic at low concentrations in water cultures.

The addition of acid calcium phosphate, or superphosphate, has a beneficial effect on soils that are already acid. Although the acidity of the soil is increased, the beneficial action may be due in part to the precipitation of the soluble and toxic aluminum and manganese as phosphates of low solubility.

Although some workers have reported that aluminum is essential for normal growth and development of plants, there do not appear to be any deficiency diseases reported as due to the lack of this element. On the other hand, some root rots are ascribed to the presence of excessive quantities. Aluminum sulphate has found some use in France as a catalytic fertilizer for over 20 years, and limited use has been made of it in the growing of such acid-loving plants as rhodendrons, azaleas, and blueberries. It has also been used to change the color of hydrangea flowers, which are normally pink on neutral soils but turn blue when sufficient aluminum sulphate or other acid-producing material has been added to the soil.

Antimony

Antimony has not been reported as occurring in plants or soils. It has been found less toxic to plants than arsenic. The use of considerable antimony potassium tartrate to control certain insect pests on citrus trees may possibly bring up a spray-residue problem similar to that of lead and arsenic.

Arsenic

Arsenic is present in all soils, varying from a few tenths of 1 part to over 500 parts per million. Most soils contain less than 10 parts. It is widely distributed in plants, from a barely detectable quantity to as much as 10 parts per million. Barley grown on western orchard soils that have accumulated considerable arsenic from sprays has been found to contain as much as 13 parts per million in the leaves and over 1,200 in the roots.

The addition of large quantities of arsenates to the soil directly or indirectly in the control of insect pests has caused a distinct arsenic problem in the Cotton Belt, in areas infested with the Japanese beetle, and in some commercial fruit orchards.

In soils in general there is no relation between the quantities of total and water-soluble arsenic. The quantity of water-soluble arsenic in natural soils and in soils to which arsenates have been added is dependent upon two things—the reaction of the soil and the quantity and nature of the clay or colloidal matter. The addition of small quantities of arsenates to acid sandy soils will give rise to such a high concentration of water-soluble arsenic that legumes will not grow. Very much larger applications fail to inhibit the growth of legumes on soils of heavier texture, especially if the clay contains an abundance of iron. In some of the western orchards it has been found that arsenic has not been leached below the depth of plowing in some 20 years. On the acid New Jersey Podzols, however,

considerable arsenic leaches or is carried from the surface to the subsoil in 1 year. In the latter soils it would appear that arsenic would be leached out by natural processes covering a period of years, while in the former it would continue to accumulate in the surface soil.

Some nitrifying bacteria are stimulated by the presence of small quantities of soluble arsenic in the soil. In higher concentrations it is poisonous to nearly all plants.

It is doubtful if it would ever be desirable to apply arsenic as a soil amendment. The problem is rather to get rid of the arsenic that has been applied as sprays or insecticides, or to render it noninjurious. For the latter purpose the addition of lime to decrease the acidity or the application of hydrated ferric oxides appear to be the only practical remedies.

Barium

In small amounts barium is present in all soils and in all plants. Quantities present in soils vary from a few thousandths of 1 percent to as much as 3.68 percent of barium oxide (BaO) (in a special soil in the vicinity of a barite mine). Only small quantities find their way into plants; tobacco has been found to contain as high as 0.15 percent and alfalfa 0.14 percent.

Barium is poisonous to plants at low concentrations. In the presence of calcium carbonate, however, considerable concentrations may occur in the soil solution without rendering the soil markedly infertile. Barium replaces other bases in soil colloids very energetically. For this reason nearly all soils contain small quantities of exchangeable barium notwithstanding the fact that there is a low concentration of barium in the earth's crust. In some soils there is so much exchangeable barium that it would seem to interfere with the absorption of sulphate by the plants through the formation of insoluble barium sulphate.

The quantities of barium taken up by the plant even from a soil high in barium are so low that there is little likelihood of animals being poisoned by eating the plant. The cattle poisoning in certain Colorado pastures that was once thought to be due to barium has been found to be due to alkaloids or to selenium.

Beryllium

Beryllium has been found in small quantities in plants growing on the island of Elbe in soils containing beryl. It has also been found in spectroscopic traces in the ash of hickory leaves growing on ordinary soils.

The characteristic beryllium mineral is beryl. That this mineral is very resistant to decomposition by the soil-forming processes is proved by the high content of beryl in soils formed from pegmatite veins. Small quantities of beryl are widely distributed in granites and it is probable that granite also contains small quantities of beryllium in other forms. It would seem that clay from granite soils should generally contain some beryllium, but this has not been demonstrated. Beryllium so much resembles aluminum that it is most difficult to determine small quantities of one in the presence of large quantities of the other.

Beryllium in very low concentrations is toxic to citrus cuttings in solution cultures.

Boron

Boron, from the standpoint of agriculture, is unique among the chemical elements in that very small quantities are necessary for the normal growth of many, if not all, plants and only slightly higher concentrations cause injury. With a number of plants the range between these two levels in water culture is only a few parts per million.

Boron is present in quantities up to 200 parts per million in all normal, healthy plants. Orchard-grown citrus leaves suffering from boron injury may contain in excess of five times as much. There are very few reliable data on the boron content of soils for the reason that the analysis of soils for the very small quantities of boron they contain is a very difficult matter. Tourmalines, which normally contain about 10 percent of boron, are universally present in soils, though commonly in very small quantity, and judging from their permanence they must be nearly insoluble.

It has recently been shown that internal cork of apples, top rot of tobacco, cracked stem of celery, heart and dry rots of sugar beets (fig. 1), and similar physiological diseases of plants are due to a deficiency of boron. These names

indicate the dominant symptoms that characterize the disturbance to growth of the crop in question. The actual quantity of boron that must be supplied on soils where the element is deficient in order to produce normal growth varies with the method of application, the season, the soil, the source of the boron, and the crop. However, the quantity should be small—in the case of tobacco, for example, about 1 pound per acre in soluble compounds with applications immediately adjacent to the plant. With celery and beets the quantity necessary may be greater. It has been reported that boron will sometimes correct injuries to alfalfa and other field crops due to overliming.

Certain European workers have pointed out that heart rot and dry rot of sugar beets are more prevalent on alkaline soils, possibly owing to the fact that certain borates are relatively insoluble, especially those of magnesium.

FIGURE 1.—Effects of boron deficiency on beet roots: *A*, Normal root; *B*, root showing heart and dry rots due to boron deficiency; *C*, section of beet root showing early stage of heart rot due to boron deficiency. (Photos by J. E. Kotila and G. E. Coons, Bureau of Plant Industry.)

It is also important to keep in mind the fact that relatively small quantities of boron become toxic under certain conditions. A few years ago, potash salts containing boron in amounts harmful to plant growth were used as fertilizer and caused damage to crops. Irrigation water occasionally contains boron in amounts toxic to plants. Considerable damage to citrus crops in California was caused by irrigation water containing more than one-half part per million of boron.

The specific effects of boron on the growth of tobacco plants are shown in figure 2. The symptom characteristic of boron deficiency may be best understood when considered as developing in progressive stages. First, the young leaves composing the terminal bud exhibit a light-green color, the bases of the individual leaves being of a lighter green than the tips. When this condition develops, the bud leaves cease to grow and manifest a drawn appearance. Following this, the tissue at the base of the young leaves breaks down and becomes brownish to black. The final result of this stage is the death of the terminal bud, but sometimes the disturbance does not progress so far and the young leaves make later growth, in which case they may be distorted or notched by twisting to one side because of the growth around the injured tissue. The stalk toward the top of the plant

also may show a one-sided or twisted growth. If the boron deficiency is not too extreme, the lateral buds (suckers) may develop in the axils of the leaves or at the base of the stalk, but they generally break down as described above. The automatic topping of the plant produced by death of the terminal bud results in a thickening and increase in area of the leaves. The upper leaves tend to roll in a half circle downward from the tip toward the base, becoming glabrous, stiff, and brittle, and when the midrib is broken the vascular tissue shows discoloration. The element boron appears to function in terminal growth or meristematic tissue

FIGURE 2.—A, Normal tobacco plant from field; B, tobacco plant from field showing boron-deficiency symptoms.

development, since those are the parts of the plants that first manifest abnormalities resulting from a shortage.

The occurrence of boron in irrigation waters and the deposits of borax occurring in the evaporated residues of surface soil water in some arid regions indicates that boron is not absorbed and held by the soil colloids. Additional evidence of this is the fact that a very slight application of borax over that needed by the plant causes injury. In this respect boron is quite different from copper and zinc, which are absorbed by soil colloids.

The inclusion of small amounts of boron in fertilizer mixtures would appear to be a desirable practice in many areas where field and orchard crops have been found to manifest sysmptoms of shortage of the element. Compounds of this element are compatible with the salts that are commonly used in fertilizer mixtures. Sodium tetraborate (borax) has been found by test to be a suitable source of the element. For some experimental work boric acid and borosilicates, finely ground, have been found to be good boron sources.

The application of such a small quantity as 1 pound per acre requires careful grinding and mixing with the regular fertilizer to insure even distribution.

Bromine

Bromine appears to be generally present in quantities of the order of a few parts per million in plants and soils. Raw German potash salts contain considerable bromine. This element supplied to plants in the form of sodium bromide shows no immediate ill effects, but later in the life of the plant the effect is quite serious. The clay of ordinary soils does not retain bromine and it would be quickly leached from the soil.

Cadmium

Very little is known of the effect of cadmium on plants or of its occurrence in soils. It is one of the very few elements that have not been reported in plant ash. Possibly the attention that is being given zinc agriculturally may result in increasing our knowledge of cadmium, which resembles zinc in many ways.

Caesium

This rare alkali has been reported in a few plants and soils in spectroscopic traces. Beyond these facts there is very little known about caesium in relation to plant growth. The caesium mineral pollucite occurs occasionally in pegmatite veins and there is a possibility that in rare cases soil masses contain notable quantities of caesium. It behaves much like potassium, and like that element it is probably absorbed and retained in the soil clay. Although this element resembles potassium it cannot be substituted for potassium to produce normal plant growth.

Chlorine

Chlorine is found in all soils and plants. A few plants, such as buckwheat, seem to require chlorine for complete development, but it is not considered essential to plant growth in general. The quantities found in soils of humid regions are generally small. In the so-called alkali soils of semiarid and arid regions crusts of various chlorides may accumulate. Chlorine is not retained by soil colloids and is easily leached out by rain water.

Plants vary a great deal in chlorine content. This element seems to act as a vehicle to carry various bases in solution into the plant. Complications resulting from this action are probably responsible for the differences of opinion as to the fertilizing value of chlorine. Plants fertilized with chlorine salts may contain several percent of chlorine, though in general plants are so deficient in sodium chloride that it is necessary for herbivorous animals and man to take considerable salt. The animal needs the chlorine of common salt as the source of hydrochloric acid in the gastric juices. Excesses of chlorine are harmful to plant growth, but small amounts have been found to protect the plant from excessive drying during drought periods. The relationship of the chlorine content of cured tobacco to the fire-holding capacity of the leaf is well recognized. When the cured leaf contains any considerable quantity of chlorine the fire-holding capacity is lowered.

Chromium

Chromium is present in all soils and in all plants. Except in some soils formed from serpentine and other ferromagnesian rocks, the quantities are very small, of the order of a few thousandths or a few hundredths of 1 percent. However, in some of the serpentine soils of Puerto Rico more than 5 percent of chromic oxide has been found, and many of the "poison spots" in Josephine County, Oreg., contain as much as 2 and 3 percent of chromic oxide.

The quantities found in plants are very small, generally at most only a few parts per million.

Chromium salts, in very small concentrations, have been found toxic to plant growth, and chromium in the form of chromates is particularly toxic. Attempts to use the spent liquors resulting from chrome tanning of leather showed these products to be very toxic. When applied to high lime soils or used in conjunction with much lime the toxic effect was largely nullified.

At least two forms of chromium occur in the soil. One form is the mineral chromite, a very insoluble ferrous chromite. This is very inactive and except in

the very acid soils should have little deleterious effect. The other form, which appears in the colloidal matter or clay, probably is isomorphous with the oxides of aluminum and iron, and becomes soluble in the same soil conditions that dissolve alumina and iron oxide.

Agriculturally, chromium must be considered a deleterious element. No plant or animal diseases due to lack of chromium have been reported, and except for the universal occurrence of minute quantities in plants there is no evidence that even small quantities of chromium are of use to plants.

Several instances of industrial chromium poisoning have been reported and some Canadian investigators have found human tumors that contained chromium.

The relatively high percentage of chromium in the soils of the Conowingo barrens and in other soils formed from high ferromagnesian rocks is at least a prominent cause of the infertility of such soils.

Cobalt

Cobalt occurs in most soils in quantities ranging up to 10 and 15 parts per million. In various plant leaves the cobalt content may be as high as 2 or 3 parts per million.

Plants do not seem to suffer from the lack of even very small quantities of cobalt. In water cultures small quantities have been found to be stimulating, but in larger concentration the element is toxic, producing effects resembling manganese deficiency.

In New Zealand it has been found that sheep suffer from a lack of cobalt in the natural vegetation in soils having less than 2 to 3 parts per million of the element. When cobalt in the soil exceeds 5 to 10 parts per million the plants take up enough to produce normal growth in the sheep. It is probable that cobalt may be a factor in certain cattle deficiency diseases in Florida that are now thought to be due to lack of iron.

Copper

Copper apparently occurs in all soils, ranging from about 1 to over 50 parts per million in normal agricultural soils. It is found in plants up to about 100 parts per million. It is especially high in some seeds and, according to spectroscopic determinations, in some mushrooms.

Copper is absorbed with considerable avidity by the clay acids, but this absorbed copper is easily replaced by some of the other bases. In fact, the use of copper salts has been proposed to determine the base-exchange capacity of soils. The relatively large applications of copper sulphate, 30 to 200 pounds per acre, that have been used to produce normal plant growth on marsh soils is a practical illustration of the absorptive capacity of the soil for copper. The presence of copper in sea water and in oysters and other sea food indicates that it is leached from the soil. On the other hand if the sulphide ion be present in soils, copper will tend to be retained as a nearly insoluble sulphide. It is not impossible that the observed beneficial use of copper salts is due in some cases to the precipitation of the sulphide ion.

Copper compounds function in plant nutrition. It has been recently found that the dieback of citrus can be remedied by applications of copper salts. The yellow tip, or reclamation disease, on the marshy soils of Europe has been corrected by copper, and in Florida and New York it has been found necessary to apply 25 to 50 pounds of copper sulphate per acre to soils high in organic matter before lettuce and other plants can be grown successfully. Abnormalities in the growth of many plants produced on peat soils have been corrected by the use of copper compounds.

It is possible to demonstrate the effect of copper on growth of plants by using the solution-culture method. For this, pure chemicals containing little or no copper are necessary, and the water used in the preparation of nutrient solutions must be redistilled to free it from traces of copper. Special containers for growing plants must be used to avoid contamination by copper compounds. Tobacco grown under these conditions with and without copper shows striking effects (fig. 3, *A* and *B*).

The plants grown without copper have a characteristic appearance. The upper leaves are unable to maintain their turgor and consequently wilt badly. These plants are permanently wilted and do not regain moisture during the night or in cloudy weather as does a plant that has wilted during a hot day. Growth

is reduced in proportion to the degree of shortage of the element and the stage of growth at which the element is withdrawn. When copper was the limiting growth factor during the flowering stage, it was observed that the amount of seed set was reduced and the seed stalk was unable to stand erect.

The copper necessary to correct the effect in nutrient solutions varied from one-sixteenth to one-eighth part per million. Amounts much in excess of these produced a decided stunting of plants. The quantities of copper that have been used on soils to correct the above-described conditions are relatively large—from 30 to 200 pounds of copper sulphate per acre. These soils have a high fixing power for copper compounds so that heavy applications are necessary to produce the desired effect, although small applications of copper as dust or spray have also produced striking results. So far as available experimental evidence

Figure 3.—Effects of mineral deficiencies on growth of tobacco: *A*, Normal tobacco plant grown in nutrient solution with copper added; *B*, tobacco plant grown in nutrient solution without copper; *C*, in sand culture without manganese; *D*, in sand culture without iron; *E*, normal tobacco plant grown in sand culture with complete nutrient solution added; *F*, in sand culture without zinc.

indicates, the action of copper compounds is not beneficial on soils other than peats or mucks.

It has been reported that copper sulphate will cure a curious form of soil infertility caused by overliming. The action of the copper in this case is obscure.

In animal metabolism copper is necessary in addition to iron to form the hemoglobin of the blood. Certain counties in Florida produce pasture grass so deficient in both iron and copper that cattle fed on it will not mature normally.

The inclusion of copper compounds in all standard fertilizer mixtures would not appear to be justified until further experimental evidence is available indicating that this element is deficient in a wider variety of soils. Soluble copper compounds would not appear to be compatible with soluble phosphates since cupric phosphate is relatively insoluble.

Fluorine

Small quantities of fluorine are found in plants, but the element is not generally considered essential to plant growth. In soils fluorine has been found in quantities ranging from traces up to 0.15 percent. Mica and tourmalines, both of which may contain up to 1 percent of fluorine, are present in practically all soils.

In some cases small quantities of fluorides have proved stimulating to plant growth.

Fluorine probably does not act like chlorine in the soil. The predominating basic ion in the soil is calcium, and since the solubility of calcium fluoride is but 16 parts per million in water, it is doubtful if the fluorine in its maximum concentration in the soil would exceed 8 parts per million, which is the amount of fluorine in a saturated solution of this salt.

Florida and Tennessee phosphate rocks contain from 3 to 4 percent of fluorine, and about three-quarters of this is retained in fertilizers made from these sources. Considerable fluorine is therefore added to soils fertilized with commercial fertilizers.

Fluorine in drinking water in excess of 1 to 3 parts per million, according to different authorities, causes mottled teeth and other physiological disturbances in animals. The effect of higher concentrations of fluorine in plants used as food for animals and man is not known. Experimental work with rats has shown that 14 parts per million of fluorine in the diet interferes with the normal development of teeth. It would appear best to reduce to a minimum the quantity of fluorine applied with commercial fertilizers. The use of fluorine compounds as insecticides is growing, and in years to come the quantity of fluorine added to soils through this source may be considerable.

Germanium

Very little information on germanium is available. Spectroscopic traces occur in the ash of marine plants, and it has been found that barley plants will take up this element. Germanium occurs in spectroscopic traces in a number of minerals. Topaz is practically never without some small quantity of germanium. The element also occurs in many zinc blends.

Gold

Gold is widely distributed in nature, mostly in very minute quantities. It has been reported that sands from the banks of the river Danube in south Slovakia contain about 0.1 gram of gold per ton, and plants growing on this sand are able to accumulate gold. The ash of corn grains contained 0.0002 percent, and the ash of *Clematis* contained 0.06 percent gold. The whole plant of scouring-rush accumulated gold to the extent of 610 grams per ton of ash. The metal is said to be concentrated in the seeds of the flowering plants.

Iodine

Iodine is unique among the elements occurring in the soil in small quantities in that a deficiency has been discovered to be of importance not by its effect on plant yields but by its effect on man and domestic animals.

The recognition of the importance of iodine in the diet for the control of certain types of human goiter has been one of the outstanding developments in recent medical science. There is a high incidence of goiter in certain regions of the world; notable among these are parts of Switzerland and of the States of Wisconsin, Minnesota, and Washington. This high incidence of goiter is associated with a very low iodine content of the soil. Soils of such regions are generally quite acid, and the highly leached clay they contain does not possess the power of anion retention, so that even the small quantities of iodine that were present in the geological strata are leached out by the percolating water. These soils may contain only a few parts per billion of iodine—not enough to grow plants with sufficient iodine to prevent goiter.

The birth of hairless pigs has been caused experimentally by feeding brood sows diets low in iodine and prevented by supplying iodine compounds. Goitrous conditions have been induced in calves experimentally by feeding rations low in iodine.

Soils developed from limestone in humid regions and those near the seacoast usually contain sufficient iodine to prevent goiter.

In some cases the application of small quantities of iodine to the soil has resulted in a slight increase in crop yield, but the main value of such additions would seem to be the increase of iodine in the leafy parts of plants that may supply the element to man directly or through meat, poultry, and dairy products.

Since iodine is so easily leached from the soil, large, infrequent applications are not as desirable as small applications made to a particular crop. Iodine is contained in many commercial soil amendments in considerable quantity. Among these are dried fish and Chilean nitrate. Seaweed contains much iodine as well as other desirable elements.

Iron

Iron has long been recognized as essential to normal plant development. In fact, it was the first of the secondary elements under discussion to be recognized as indispensable to plant growth under field conditions. Iron is directly connected with the functioning of the chlorophyll. In the leaves of healthy plants iron will average a few hundredths of 1 percent, the amount never varying greatly. The iron content of plants is relatively constant compared to that of manganese and aluminum.

Although there is an abundance of iron in nearly all soils, the exchangeable iron in calcareous and other soils around the neutral point may be so low that the plants are unable to absorb enough for healthy growth. Besides the iron of the undecomposed silicate minerals in the soil, there are two other general forms, the iron of the colloidal clay or absorption complex, and iron in the form of oxide, both hydrated and anhydrous. The iron in the colloidal clay behaves much the same as aluminum.

The solubility of iron in the soil is governed by the reaction of the soil, the element being comparatively soluble in very acid soils, and also by the prevalence of oxidizing and reducing conditions. Iron in the form of hydrated iron oxide, particularly, is easily reduced under some soil conditions and remains in solution as ferrous bicarbonate. The submerged soil conditions that occur during very wet weather are favorable for the solution and transportation of iron in the soil solution, and in extreme cases the concentration of iron may exceed the toxic limit. Deep-rooted plants would appear to have considerable soluble iron at their command, for the zone of submergence is above the permanent water table many times during the year.

The addition of any reducing organic matter such as crop residues and stable manure increases the supply of available iron in the soil. The iron is temporarily reduced and made soluble, and the complex ions formed with the organic matter hold the iron, even after oxidation, in solution at pH concentrations that would otherwise precipitate ferric hydroxide.

The distinctive chlorosis (fig. 3, *D*) resulting from a shortgage of iron was early recognized and was for a long time considered to be the only type of chlorosis in plants.

It has been reported from Hawaii that soils of high manganese content do not furnish sufficient available iron for normal plant development. The most effective method found for correcting this condition is the application of iron as a spray. With pineapples the quantity to control chlorosis may be four applications a year of an 8-percent solution of ferrous sulphate.

The crops grown on some Florida soils are so deficient in iron that cattle fed only on these crops show marked iron-deficiency diseases.

Soluble iron compounds are not compatible with soluble phosphates in fertilizer mixtures since they form insoluble compounds that are largely unavailable to plants. Soils having considerable iron in an unavailable form could be treated with acid-forming fertilizers such as ammonium sulphate or elemental sulphur to increase the acidity. Liberal applications of organic matter also increase the availability of the iron. Overliming is productive of chlorosis, and with plants susceptible to iron chlorosis lime should be sparingly used.

Lead

Lead in very small quantities is of general occurrence in plants and soils. Normally the quantities in edible plants or parts thereof are so small as to have no effect on the health of the animal eating the plant. However, the accumulation

of lead in the soil from spray residues may be of sufficient magnitude in some soils to raise the lead content of food plants to a dangerous point. Lead is a cumulative poison, and small quantities that by themselves cause no harm become dangerous when taken constantly.

Lead is "fixed" by the clay of the soil, and it would appear that the sulphate, sulphide, phosphate, and carbonate ions should render lead added to a normal soil so insoluble as to be inactive. Very acid soils, however, would increase the solubility of the lead. In some Oregon orchard soils it has been found that lead has not been carried down below the plow depth after the orchards had been sprayed for 20 years with lead arsenate.

Soluble lead compounds are toxic to plants except in very low concentrations, at which in some cases they seem to have stimulated growth. In some commercial apple orchards the residues from lead arsenate sprays have accumulated to such an extent that green manuring crops can no longer be grown. It is supposed that arsenic is chiefly responsible for this condition, though lead may be a contributing cause.

Lithium

Lithium occurs in plant ash almost universally but in very small quantities. In soils the quantities present have been found to vary from a spectroscopic trace to over 100 parts per million in ordinary agricultural soils.

Some field experiments show that very small applications of lithium salts are frequently stimulative; larger concentrations have proved toxic. Tobacco and potatoes are less susceptible to injury by lithium than many other crops. Lithium when applied in any considerable quantity to the soil in the form of soluble salts produces toxic effects on tobacco resulting in well-defined spotting of the lower leaves.

Many lithium minerals occur in pegmatite veins. Since these characteristic lithium minerals appear to alter or weather easily, it is doubtful whether many soils will contain more than a trace of this element. Tourmaline, however, which may contain as high as 1.5 percent of lithia, is quite resistant. Lithium appears to act in the same manner as sodium toward the soil colloids and is not absorbed like potassium.

Magnesium

Magnesium is essential to plant growth. It is a part of the chlorophyll molecule. Chlorophyll contains slightly less than 4 percent of magnesia. As a rule healthy plant leaves contain about 0.5 percent of magnesia.

Surface soils generally contain less than 1 percent of magnesia, though special soils derived from serpentine have been found to contain more than 30 percent. A large part of the magnesia of soils is found in the colloidal fraction, and only about one-fourth or one-fifth of this is in the exchangeable or soluble form. A variable quantity of magnesia is in the hornblendes, micas, etc., of the sands and silts. A very few soils contain fragments of dolomite, a double carbonate of magnesium and calcium. One very unique soil from California contained magnesium carbonate.

One of the first deficiency diseases noticed in the field was the sand drown of tobacco. Sand drown was first recognized and reported in 1922 by Garner and coworkers. This is definitely a magnesium deficiency and generally occurs on the sandy Coastal Plain tobacco soils, which contain less than 0.2 percent of magnesia. A magnesium-deficiency disease of potatoes has also been found on the sandy Coastal Plain soils and on the highly fertilized potato soils of Maine where the fertilizer used contains much lime and little or no magnesia.

Plants develop a characteristic chlorosis when the magnesium supply is insufficient. The lower leaves of the plant are the first affected. The grasses, represented by the corn plant, manifest a streaking due to the loss of chlorophyll between the veins at the leaf tip and margins. Tobacco and other plants also manifest a loss of green color between the veins beginning at the leaf tip and margins. With cotton, this loss of green is followed by the development of a red color.

Soils containing a large excess of magnesium over lime have been found to be infertile. This has been explained as the result of an unfavorable ratio of lime to magnesia where the magnesia is in excess. The explanation is not entirely satisfactory, however, for a paucity of potash and phosphoric acid and a relatively great concentration of toxic elements, such as chromium, nickel, and cobalt, apparently always accompany an excess of magnesia.

Kainite and other potash-bearing salts contain considerable magnesia, and when these salts are used in fertilizers in sufficient amounts, no magnesium deficiency should occur. Magnesium limestones are commonly used as a soil amendment to supply magnesia. Water-soluble magnesium compounds that furnish 10 to 40 pounds of magnesium oxide per acre have been found to be adequate on soils deficient in magnesium, but larger quantities of magnesium limestone are necessary.

Manganese

Manganese is a common constituent of soils and plants, the quantities present in both varying greatly. In many soils and plants, manganese is a major element. Certain Hawaiian soils contain as much as 15 percent of manganous oxide, and some soils in the United States contain several percent. Some plant leaves contain as little as a few thousandths of 1 percent, and a number of tree leaves growing on very acid soils contain nearly 0.5 percent.

Defects in analytical methods are responsible for many misconceptions concerning the agricultural role of manganese. The old bromide method is not reliable, for it permits considerable manganese to escape detection, but the colorimetric method now almost universally used is quite accurate.[4]

Some soils contain only a very small quantity of manganese; others containing much manganese may have it in an unavailable form such as the very insoluble dioxide. The latter condition obtains in alkaline soils such as marls and calcareous soils, and in any soils immediately after heavy liming.

There is no correlation between the total manganese in soils and in the plants growing on the soils. The availability of the manganese is governed rather by the acidity and the reducing action in the soil than by the quantity present. White oak leaves growing on an acid podzolized soil of 0.004 percent of manganese oxide content took up 0.308 percent of manganese oxide, while the same kind of leaves on a limestone soil with 0.23 percent of manganese oxide took up but 0.020 percent. The exchangeable manganese of forest leafmold commonly equals and sometimes exceeds the exchangeable calcium.

The manganese in soils containing organic matter becomes very soluble when these soils are submerged for relatively short periods. Under these conditions the concentration of soluble manganese greatly exceeds the limits that have been found toxic to plants.

The recognition that manganese is an essential element for normal plant development has been confirmed by numerous investigators in the past few years. The gray speck of oats has been attributed to a shortage of this element in some soils. It has been found possible to cure the chlorosis of tomatoes and produce a normal growth on the calcareous soils of Florida by applications of manganese. Pahala blight of sugarcane in Hawaii appears to be correlated with a manganese deficiency. The characteristic effects of manganese shortage on the growth of tobacco plants are shown in figure 3, *C*. Considerable dwarfing is usually evident, and associated with this is a chlorosis of the upper leaves on the plant followed by a necrotic spotting, the tissue of the spots frequently dropping out. Essentially these same symptoms have been reported on tomatoes, beans, and oats.

The quantity of manganese that must be supplied on soils to correct the effects of shortage may vary, but additions of 25 to 50 pounds of manganous sulphate per acre have resulted in remarkable increases in crop yield on certain soils. Some of the variations are undoubtedly due to differences in the reaction of the soil. On acid soils, injury to tobacco by excessive quantities of manganese has been noted.

It appears desirable that soluble compounds of manganese be applied separately and not in fertilizer mixtures containing soluble phosphates, since phosphates of this element are only slightly soluble.

Rations carefully freed from manganese produce a condition in test animals that seriously interferes with normal lactation. Bone deformities, resulting in a

[4] Fortunately the bromine method is now seldom used, but the literature, particularly on the ash composition of plants, contains considerable data obtained by this method. In this old method the manganese is precipitated by boiling the slightly alkaline filtrate from the iron group precipitation with bromine water. The entire quantity of manganese in the plant may escape precipitation, and if the iron group is not carefully precipitated some manganese is lost with it. No plant has yet been analyzed by the colorimetric method that has not shown the presence of some manganese. With this method no group separations are made and the determination is made on a separate sample or aliquot part of the solution of the whole sample. All the manganese is oxidized by powerful oxidizing agents, such as sodium bismuthate, ammonium persulphate, or potassium periodate, to purple permanganic acid. The quantity of manganese present is determined by comparing the depth of color with a known quantity of manganese in the form of permanganic acid.

condition known as "slip tendon," have been produced in chickens by feeding rations low in manganese. Bones of chickens on this ration have been found to contain only about one-third as much manganese as normal chicken bones.

Molybdenum

Molybdenum has been found in very small quantities in a number of plants. In chickpea seeds as much as 9 parts per million has been found; in other legume seeds it ranges from this amount down to 1 part per million. In other plants, molybdenum appears to be present in quantities of less than 1 part per million. A few soils have been reported to contain a trace of molybdenum.

Small quantities of sodium molybdate greatly stimulate the nitrogen-fixing power of soils, and in an experiment recently carried out at Ithaca, N. Y., molybdenum gave the greatest increase in growth of some 35 trace elements tested. Molybdenum has been found to be toxic to some higher plants when present in any considerable concentration.

In Wyoming it has been found that wheat takes up molybdenum when sodium molybdate is added to the soil in which it is grown and that the wheat grains so grown are poisonous to cattle.

Nickel

Nickel is present, generally in minute quantities, in all soils and probably in all plants. The comparatively recent discovery of a specific organic precipitant for very small quantities of nickel, dimethylglyoxine, has made it possible to determine minute quantities of this element with accuracy.

Several soils derived from ferromagnesian rocks have been found to contain nearly 0.5 percent of nickel oxide. The quantities found in normal soils, however, will range from a few parts per million to a few thousandths of 1 percent. Plants seldom contain more than 2 or 3 parts per million.

In all but the most minute concentrations, nickel is toxic to plant growth, and the waste waters from mines where nickel ores are crushed have been the cause of serious complaints from neighboring farmers.

Nickel would appear to be one of the causes of infertility observed in soils formed from high ferromagnesian rocks.

From an agricultural standpoint, nickel may be considered a deleterious element. No deficiency diseases are now known to be due to a lack of nickel, and if future research should show that very minute quantities are necessary to plant growth, all soils, with the possible exception of very sandy leached soils, should contain enough of the element to supply plant needs.

Radium

Considerable work has been done on the effect of radium on plant growth.

While some stimulation in growth has been reported as resulting from the application of radioactive wastes to soils, the consensus of opinion is that such applications are without desirable effect. These applications of radioactive residues increase the radioactivity of the soil to an inconsequential degree compared to the natural radioactivity, so that no increase in yield could be expected.

Exposure of seed to radium emanations, if not continued too long, hastens the maturity of the plant after germination. Some commercial success has been obtained by treating sweet corn seed with similar emanations from electrical sources for regions in which the growing season is short.

Rubidium

Rubidium closely resembles potassium and probably enters into much the same reactions in soils and plants as that element.

Rubidium can be detected spectroscopically in all soils and in all plants. The quantities present run from spectroscopic traces to several hundredths of 1 percent. Soils developed from pegmatite veins may contain relatively large amounts of rubidium, and on such soils plants will contain considerable quantities of this element.

Rubidium is probably absorbed by the colloidal matter of the soil and held against leaching even more tenaciously than potassium. Thus, it is probable that even the small quantities of rubidium that may be present in the original rock will persist in the clay or colloidal matter formed from the rock.

In small quantities, rubidium has been found to be stimulating to plant growth, but it does not seem to be able to replace potassium.

Selenium [5]

Selenium closely resembles sulphur, but unlike this sister element, it is very poisonous to animals—even more so than arsenic. Selenium is toxic to most plants, also, though some species are tolerant of or possibly under some conditions even partially dependent upon it for normal development.

The cause of the alkali disease of cattle prevalent in the grazing sections of some of our Western States has now been shown to be selenium.

Selenium is present in detectable quantities in all soils, but it reaches toxic concentrations only in those derived from the Cretaceous shales in semiarid climates. On a seleniferous soil, one species of *Astragalus* has taken up as much as 1.49 percent of selenium. Field-grown wheat has been found to contain as high as 30 parts per million, and cabbage raised in the greenhouse on soils to which sodium selenate had been added contained 758 parts per million in the leaves. It has been observed that plants normally high in sulphur absorb much more selenium than those low in sulphur. This suggests a functional relationship between the two elements.

Selenium appears to have a rather definite reaction with some components of the soil. With ferric oxides it forms a basic ferric selenite so insoluble that plants grown on ferruginous soils containing several parts per million of selenium may be essentially free from this element.

In the form of potassium sulphoselenide, selenium is very effective in the control of the red spider. In semiarid and possibly in humid climates, however, this use of selenium is not recommended when there is any possibility of using the soil thus contaminated for growing food crops.

In greenhouse experiments, sulphates inhibit the intake of selenium by plants, but in field experiments the application of various forms of sulphur has not been successful in materially decreasing the intake of selenium by some grains. The sulphate content of seleniferous soils is generally high. However, it is of interest that certain plants manifest some symptoms produced by selenium toxicity that are also characteristic of sulphur deficiency.

Silicon

Silicon occurs in the largest quantities in the various grasses. In the scouring-rush it is the major ash constituent.

Silicon in the forms of quartz, undecomposed silicates, and various hydrated silicates or clays is commonly the major soil constituent. In some lateritic soils of the Tropics the silica content may be less than 5 percent. Silica is always present in plant ash, but in varying quantities.

Normally, silica is quite insoluble. Its solubility is increased by the presence of alkalies and by high temperatures. Silicon, in its more active forms in the soil, increases the availability of phosphorus. With alumina, ferric oxide, and water it makes up the main bulk of the soil colloids or clay. The properties of the soil colloids are largely dependent upon the ratio of silica to alumina.

Plants, particularly the grasses, grown in the absence of silica are especially susceptible to fungous diseases, and from this it is supposed that the normal plant is able to ward off such diseases because of the mechanical protection afforded by the silica in the outside walls of the plant.

While silica is not poisonous, cases have been reported where cattle have died as a result of lacerations of the walls of the digestive tract from the sharp siliceous spikes of rice hulls. Silica in the form of sand ingested by horses and cattle eating grain directly on sandy ground or drinking from shallow streams causes sand colic, which is frequently fatal.

The silicosis that occasionally causes death of miners and industrial workers is caused by silica dust in the air and not by silica in food plants.

Silver

Mushrooms have been reported to contain as much as 100 parts per million of silver, as determined by the spectroscope, and it has been reported in other plants. Little is known about the occurrence of silver in agricultural soils.

Silver salts seem to be toxic to plant growth.

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[5] For a more detailed discussion of this subject see Selenium in Soils, p. 830.

Sodium

Sodium is a common constituent of plants, but in most cases the quantities present do not exceed a few tenths of 1 percent. In soils there is seldom more than this quantity except where undecomposed sodium minerals are present in the sands and silts or where the clay has been saturated by sodium.

Sodium is not retained by soil colloids where there is much opportunity for leaching. The sodium released by the decomposition of the various sodium minerals is washed away in the drainage water and appears in the form of salt in the sea. In semiarid regions where alkali crusts are formed, the soils are profoundly altered in their properties by the reaction of the sodium salts with the clay acids, which renders the clay very impervious to water.

Some experiments show that the addition of salt has increased the growth of crops. The phenomenon of base exchange enters here, and the salt addition may have released other elements of more direct use to the plant. In the plant potassium greatly exceeds sodium, while in the blood of the animal the reverse is true. From the standpoint of herbivorous animals, practically all agricultural crops are deficient in sodium, and for ages this deficiency has been supplied by the addition of salt directly to the diet.

Strontium

Strontium is closely related to calcium and barium. In the 10-mile depth of the earth's crust there is about 0.018 percent of strontium compared with 3.65 percent of calcium. Strontium is widely distributed in soils, but in small quantities of the order of 0.05 percent. Plants contain roughly one-fifth as much.

Strontium probably reacts like barium with the colloidal matter of soils. One would expect it to be absorbed rather energetically and to displace some of the other bases present in greater quantities. Such a reaction would account for the persistence of small quantities of strontium in the soil.

Strontium does not seem to be essential to plant growth. In water-culture experiments it can only partially replace calcium in the plant. Strontium salts are toxic to plant growth in all but relatively small concentrations, but not so toxic as barium salts.

Sulphur

Sulphur is present in all plants in considerable quantity and is necessary for their growth. In high-protein grains like wheat it runs generally over 0.3 percent, and in cabbage and broccoli it reaches a concentration of several percent. The sulphur content of soils is comparatively low, generally running between 0.1 and 0.3 percent.

A large part of the sulphur in the soil appears to be contained in the organic matter. The part present as sulphate ion is not strongly held by the ordinary clay of the soil but is easily leached out and appears as sulphates in the sea. In semiarid and arid regions, calcium sulphate (gypsum) and even the more soluble sodium sulphate frequently occur as soil components. When soils are submerged under water for some time, sulphates are reduced to sulphides, hydrogen sulphide is given off, imparting a characteristic odor, and the soil becomes very toxic owing to this component and others.

A general survey of the sulphur and phosphorus content of crop plants and soils reveals the fact that soils in general are more deficient in sulphur than in phosphorus. It seems strange, then, that so little attention has been directly given to sulphur as a fertilizer constituent. The fact is that sulphur has been applied more or less unconsciously with phosphorus in the forms of superphosphate and acid-treated bone. In superphosphate, the sulphates commonly exceed the phosphates. Largely because of this, sulphur deficiencies in soil have not appeared. The use of highly concentrated fertilizers in which the phosphates carry no sulphates will create a sulphur deficiency unless sulphates are added.

The atmosphere contains considerable quantities of sulphur compounds, which are brought down by rains and function in the nutrition of plants. It is possibly for this reason that a sulphur shortage has not become generally acute. In the arid regions of the West, sulphur deficiency has been found in alfalfa and other crops and corrected by the use of sulphur compounds. Effects of sulphur deficiency in plants are characterized by loss of green color in the younger leaves of the plant, including the veins. In extreme cases all the leaves may be light green

in color, including the veins, but the lower leaves do not dry up as they do in the case of nitrogen deficiency, which is evidenced by a light-green color accompanied by yellowing and drying up of the lower leaves. The yellows disease of the tea bush has been shown to be due to a deficiency of sulphur.

Thallium

Thallium is of interest largely because of its use in poisoning grain and other bait for rodent control. When this poisoned bait is scattered on the soil, the effects persist for several years. Thallium is poisonous to both plants and animals, and it should be used only under expert supervision. Little is known of its natural occurrence in plants and soils. When artificially applied, it is probably taken up by the plant, and as little as 35 parts per million in sandy soils has practically prevented the growth of plants. Whether this element is stored in the edible parts of plants in quantities sufficient to be toxic to man and animals is a question for further research to determine. Thallium compounds have been used as depilatories with disastrous effects.

Titanium

Small quantities of titanium, of the order of a few parts per million, are found in plants. It is almost a major constituent of soils; few soils contain less than 0.5 percent of titanium dioxide, and some Hawaiian soils contain as much as 10 percent. The major part of the titanium in soils seems to be of an inert nature resembling silica.

The leaves of plants contain a few parts per million of titanium, and like iron, aluminum, and zinc, titanium follows the concentration of the chlorophyll when the composition of the blanched and green leaves of cabbage and lettuce are compared.

Vanadium

Considering the resemblance of this element to phosphorus, there is surprisingly little vanadium in plants. There is some geological evidence that in the past plants or animals have concentrated vanadium. Some Peruvian shales contain up to 0.5 percent of vanadium pantoxide. Analysts have found that the ash of several peculiar samples of cannel coal have yielded values of vanadium pentoxide ranging from 35 to 38 percent. Asphaltic substances in many localities contain considerable vanadium. The same may be said of petroleum products, and there is considerable evidence that, in past geological ages at least, vanadium has been concentrated by biochemical processes.

Vanadium is present in agricultural soils in quantities ranging from 0.01 to 0.1 percent. In the analysis of a series of 48 plants, only 4 showed the presence of more than 10 parts per million of vanadium. These were pine needles, beets, and bean and clover plants.

Vanadium is concentrated in sandstones and other sedimentary rocks and in clays. With the soil colloids, it would be expected to behave much like phosphorus.

Vanadium is reported to be absorbed by some invertebrates as a substitute for copper and phosphorus in their blood.

Zinc

Zinc is widely distributed in plants and other biological material. In the general run of vegetables, quantities present range from 1 to 10 parts per million. In cereals and legumes, 10 to 50 parts are commonly found. Ordinarily forest tree leaves have been found to contain from 2 to 240 parts per million of zinc. A certain variety of European wild violet (*Viola calaminaria*) tops the list of zinc imbibers. Liver and oysters are especially high in zinc, and maxima of 339 and 341 parts per million, respectively, have been noted.

This metal seems to be present in all soils in minute quantities. Various analyses show from 2 to 50 parts per million. The lowest quantities are found in sandy soils.

It has been proved that zinc is essential to the normal development of wheat, barley, beans, and buckwheat, and it is probably necessary for the normal development of other plants. It has been found possible to produce distinctive effects on the growth of the tobacco plant in sand or solution cultures by withholding zinc.

The effects are characterized by a spotting of the lower leaves of the plant, which in extreme cases has resulted in almost total collapse of the leaf tissue (fig. 3, *F*). The lower leaves of the plant first develop a faint chlorosis. The break-down of leaf tissue typically follows and proceeds rapidly after it has begun, developing more rapidly during cloudy periods than when the weather is normal. These characteristics correspond to a break-down that occurs very extensively under

FIGURE 4.—Rosetted pecan trees on zinc-deficient soil. Foliage and limb on upper left have been treated with solution of zinc sulphate. (Photo by A. O. Alben, Bureau of Plant Industry.)

field conditions during wet periods when a large proportion of the crop frequently succumbs to a leaf spot that has commonly been attributed to bacterial invasion. It is not possible to say at the present time whether zinc deficiency enters into the complex, but research is in progress to determine this.

The necrotic areas that develop on leaves of tobacco plants when zinc has been withheld commonly begin at the leaf tips and on the lower leaves of the plant, although there are instances where the bottom leaves of the plant may not be the first involved, nor have the lesions always been localized at the leaf tips. The lesions usually involve a very small area at first and in some instances are surrounded by a halo. These areas characteristically soon develop a brown color. Frequently the small veins, which at first are not involved, soon break down, as does the entire leaf tissue.

While it is recognized that small amounts of zinc are essential to plant growth, larger quantities are toxic to most plants.

Zinc resembles copper so far as reactions with the soil colloidal matter are concerned. Zinc is absorbed by the soil colloid and a part is held in the exchangeable condition. Zinc phosphate is so nearly insoluble at hydrogen-ion concentrations generally found in the soil that the phosphate ion will reduce the availability of zinc salts. In neutral or alkaline soils, zinc phosphate is so very nearly insoluble as to account for observed unavailability of zinc in such soils.

Pecan rosette, shown in figure 4, citrus little leaf and similar troubles of deciduous trees, the bronzing of the leaf of tung trees, and white bud of corn are ascribed to zinc deficiencies. Very marked effects on growth and correction of the troubles mentioned have been reported from the use of zinc compounds. The exact significance of these compounds in this connection does not appear to be clear, since large applications are required to correct the condition. If the element were functioning as a nutrient, relatively small applications should be sufficient, provided precipitation did not render unavailable the zinc compounds added. However, it has been shown in work with citrus and pecans that injections into the trunk of the tree and dipping and spray applications to the leaves are effective, indicating that the element does act as a plant nutrient.

SELENIUM is particularly important among the secondary elements in the soil because it causes the fatal sickness known as alkali disease of cattle. For 75 years the disease was a mystery. This article tells how the cause was discovered, where the disease occurs, and what is known about it today.

Selenium in Soils

By K. T. Williams [1]

FOR MANY YEARS a disease of animals, apparently peculiar to certain portions of South Dakota and adjacent areas, has been recognized and described under the name "alkali disease." The symptoms are loss of hair and hoofs, lameness, liver lesions, and edema, and the rate of mortality among affected livestock is high.

For more than 75 years the cause of alkali disease was unrecognized. The first known written mention of it is found in a statistical report by Madison (*234*)[2] on sickness and mortality in the Army of the United States, dated September 1857. Dr. Madison described a "very fatal disease" which manifested itself among the cavalry horses at Fort Randall in the then Nebraska Territory. He gave a very satisfactory description of the symptoms and correctly ascribed the origin of the trouble to the pasturage. In later years the disease was supposed to be caused by the water of the area. Because of the frequent loss and still more frequent illness of cattle, this supposed source of the disease was investigated at the South Dakota Agricultural Experiment Station, and the harmlessness of the water in this particular respect was established.

In 1928 Kurt W. Franke, station chemist of the South Dakota Station, began a series of investigations which definitely determined that the disease in question is produced by the consumption of grain and other vegetation grown upon definite soil areas.

As a result of a conference between Franke and Henry G. Knight, Chief of the Bureau of Chemistry and Soils, a cooperative study of the problem was begun in 1931. At the suggestion of Knight, W. O. Robinson of the Bureau was asked to determine the presence or absence of selenium in a sample of toxic wheat. By a method that he devised for the detection of selenium in small amounts in vegeta-

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

tion, Robinson was able to show that selenium was present in the toxic wheat to the extent of 10 to 12 parts per million (*314*). He found that nontoxic wheat grown in Virginia and Maryland contained no selenium. Horn, Nelson, and Jones (*171*) found that the gluten contained nearly all the toxic principle, and Robinson found most of the selenium in the gluten. He found that the hoof of an animal that had died of alkali disease contained a relatively large amount of selenium and the hoof of a healthy animal contained none. Shales, soils, and vegetation from the toxic area contained selenium. Research on the subject rapidly expanded in the Department of Agriculture and in several State experiment stations.

Survey work has shown that certain Cretaceous geological formations are the parent material for most of the toxic soils. Soils derived from some Permian and possibly Triassic geological formations are also seleniferous (selenium-bearing). The seleniferous soils of the United States, that is, those capable of producing toxic vegetation, are apparently confined to areas of low rainfall (20 inches or less per year). It seems that in areas of high rainfall percolating water keeps available selenium below the toxic limit. Toxic areas have been located and to some extent delimited in South Dakota, Nebraska, Wyoming, Kansas, Colorado, New Mexico, and Montana (*57, 58, 59*).

In most cases the geological formations from which these toxic soils are derived contain less than 10 parts per million of selenium. Soil with 1 part per million or even less may produce vegetation containing sufficient selenium to be toxic. Tables 1 and 2 give selected data for geologic and soil profiles.

Plant species vary widely in the quantity of selenium they absorb. Table 3 gives an idea of the variations that may be expected in the selenium content of the vegetative growth on toxic soils.

Table 1.—*Selenium content of representative samples from profiles of geological formations that give rise to the majority of the seleniferous soils of the United States*

PIERRE FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
	Feet	*Inches*	*Parts per million*		*Feet*	*Inches*	*Parts per million*
Shale	2	--	28	Bentonite and gypsum	--	1	22
Do	3	--	52	Gypsum streak	--	--	5
Siltstone	--	1	26	Shale	6	8	28
Ironstone and mudstone	4	--	14	Limestone and chalk	10	1	1.5
Do	3	--	4	Bentonite	--	1-2	9
Do	--	3	8	Shale	2	--	8
Ironstone and shale	1	6	10	Bentonite	--	¼	76
Do	2	6	20	Shale	2	--	103
Do	2	6	14	Limestone	1	--	12
Shale	4	6	23	Do	1	3	46
Do	4	--	14	Bentonite	-	1	26
Do	1	--	16	Shale	3	3	24
Do	3	--	3	Mudstone and shale	2	8	28
Do	3	--	14	Shale	1	--	3
Do	3	--	28	Do	2	--	7
Ironstone and mudstone	1	6	10	Bentonite	--	10	2
Shale	4	--	21				
Do	3	--	26				
Do	4	--	21				

Table 1. ***Selenium content of representative samples from profiles of geological formations that give rise to the majority of the seleniferous soils of the United States*—Continued**

UPPER PORTION NIOBRARA FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
	Feet	*Inches*	*Parts per million*		*Feet*	*Inches*	*Parts per million*
Chalk	3	--	12	Chalk	4	--	20
	3	--	8		2	--	8
	6	--	20		2	--	28
	3	--	30		2	--	16
	1	--	25				

LOWER PORTION NIOBRARA FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
Sandstone	(1)		0.5	Limestone	(1)		0.3

CARLILE MEMBER OF BENTON FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
Yellow sandstone	(1)		0.2	Gray shale	(1)		0.7
Gray shale	(1)		1.0				

GREENHORN MEMBER OF BENTON FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
Clay shale	25	-	3.0	Dark-gray shale (with thin seam of limonite)	--	7	2.5
Dense dark-gray shale	--	14	.8	Gray clay shale	--	8	1.0
Dense dark-gray limestone	--	7	1.0	Dense dark-gray limestone	--	9	1.0
Gray clay shale		13	.7	Limonite (with bentonite)	--	2	8.0
Do	-	12	.4				
Bentonite	-	7	1.0				

GRANERÓS MEMBER OF BENTON FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
Dark-gray shale	4	--	2.5	Bentonite layer	(1)		3.0

[1] Not determined.

Table 2.—*Variation of selenium content with depth in seleniferous soil profiles*

Type and location	Depth	Selenium content	Type and location	Depth	Selenium content
	Inches	*Parts per million*		*Inches*	*Parts per million*
Fort Lyons silt loam, Prowers County, Colo.	0- 6	0.7	Pierre clay loam, Crowley County, Colo.	0- 1	2.0
	6-12	.8		1- 6	2.0
	12-24	.8		6-12	.8
	24-36	.8		12-24	1.0
	36-48	1.0		24-36	10.0
	48-60	1.0		36-48	5.0
Niobrara clay loam, Gove County, Kans.	0- 6	2.0	Boyd clay loam, Lyman County, S. Dak.	0- 8	3.5
	6-12	1.5		8-12	4.0
	12-18	1.5		12-24	5.0
	18-24	3.0		24-36	6.0
	24-60	1.0		36-48	8.0
Pierre silt loam, Mora County, N. Mex.	0- 2	4.0		48-60	12.0
	2- 6	1.0			
	6-12	.7			
	12-22	.7			
	22-30	.6			
	30-36	.7			

Table 3.—*Selenium content of various plants collected simultaneously from the vegetative growth on gritty clay loam with a selenium content of 2 parts per million, Kiowa County, Colo.*

Type of vegetation		Selenium content	Type of vegetation		Selenium content
Botanical name	Common name		Botanical name	Common name	
		Parts per million			*Parts per million*
Aplopappus fremontii	Goldenweed	320	*Helianthus annuus*	Sunflower	2
Astragalus pectinatus	Narrowleaf milk-vetch.	4,000	*Malvastrum coccineum.*	Scarlet mallow	1
Bouteloua gracilis	Blue grama	2	*Munroa squarrosa*	False buffalo grass.	4
Zea mays	Corn	10	*Salsola pestifer*	Russian-thistle	5
Euphorbia sp.	Spurge	10	*Stanleya pinnata*	Stanleya	330
Gutierrezia sarothrae	Turpentine weed	70	*Xanthium* sp.	Cocklebur	6

From the analysis of several thousand samples of seleniferous vegetation it appears that plant species may be grouped with reference to their relation to selenium absorption as follows: (1) Plants that absorb selenium readily and appear to be able to utilize it in their physiological activities. This group includes *Astragalus racemosus*, *A. pectinatus* (narrowleaf milkvetch), *A. bisulcatus* (two-groove poison-vetch), *A. carolinianus*, *A. grayii*, and perhaps others, but not all species; also *Stanleya pinnata* and *S. bipinnata*, *Aplopappus fremontii* (goldenweed), *Aster parryi* (woody aster), and probably others. (2) Plants that grow fairly well on seleniferous soils, though not entirely without injury, and are able to absorb moderate to large quantities of selenium. Among such plants are the common cereals and a number of native plants such as *Aster ericoides* (wreath aster), *A. fendleri* (blue aster), *Gutierrezia sarothrae* (turpentine weed), *Helianthus annuus* (sunflower), and *Salsola pestifer* (Russian-thistle). Members of a third group absorb selenium only in small quantities when growing on seleniferous soils and appear to have only a limited tolerance for it. Included in this group are grasses in general.

The selenium content of a given species has no constant ratio to the selenium content of the soil on which it grows. Table 4 gives data on this variation.

Vegetation from several irrigation projects was found to have a relatively low selenium content as compared with the vegetation on adjacent unirrigated soil of similar selenium content.

Hurd-Karrer (*174*) found that sulphates inhibit the selenium absorbed by plants on artificially selenized soils. Franke (*113*) and Beath (*26*) found that selenium absorption by vegetation grown on the seleniferous soils of South Dakota and Wyoming was not inhibited by the application of sulphur or sulphates.

Examination of several samples of soil and vegetation from different parts of the world indicates that the occurrence of selenium is widespread. In the United States the toxic soils are in arid and semiarid regions where the lands are devoted primarily to grazing and, to a less extent, to wheat growing. Native range animals normally tend to avoid the toxic plants, but shortage of forage caused by overgrazing forces them to eat vegetation they would otherwise avoid. Range animals brought from other areas into the seleniferous regions are

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especially susceptible to injury from toxic vegetation. Heavy losses of transient animals have been known to take place in a single night on limited areas where toxic vegetation was abundant.

Table 4.—*Selenium content of plants grown on soils containing different quantities of selenium*

Kind of vegetation	Selenium content of vegetation	Selenium content of soil (0–8 inches)
	Parts per million	*Parts per million*
Astragalus bisulcatus (two-groove poisonvetch)	6,530	6.0
	50	5.0
	4,300	4.0
	150	4.0
	2,050	2.0
	60	2.0
	3,030	.8
	510	.8
	130	.7
Salsola pestifer (Russian-thistle).	160	5.0
	35	4.0
	2	3.5
	12	2.0
Salsola pestifer (Russian-thistle)—Continued.	3	2.0
	40	1.0
	35	.5
	1	.5
Bouteloua curtipendula (Side-oats grama)	2	8.0
	10	6.0
	14	5.0
	2	5.0
	4	2.0
	0	.8
	2	.7
	1	.2

In certain areas farmers have long known that animals become affected when fed exclusively with grain grown on particular fields. However, when this grain is mixed with nontoxic grain from other fields, the trouble is eliminated or greatly reduced.

The effects of the food consumed by persons residing in the toxic areas are being investigated by the United States Public Health Service. It has been found that many individuals who show a definite intake and excretion of selenium have at the same time certain characteristic symptoms of disease. No definitely known acute cases of human poisoning have been discovered in the United States, but some have recently been found in Mexico. Among the reasons for the small incidence of poisoning in our seleniferous areas are the extensive use of other than home-grown foods and the fact that irrigation greatly diminishes the absorption of selenium in foodstuffs grown on seleniferous soils. Danger from flour made from toxic wheat seems remote, as ordinarily large quantities of wheat from different areas are mixed before the grain is milled. It seems probable from available data that such hazard as exists in seleniferous areas is in the consumption of meat, eggs, and milk produced in very toxic localities.

THIS ARTICLE *tells how native plants can be used under some conditions as a guide to the nature of the soil; describes the plant and soil correlations throughout the United States; and lists plants that indicate soil moisture conditions, good agricultural or grazing land, and {in the West} land that is good, medium, or poor for small grains, forage, and grazing.*

Plants as Soil Indicators

By H. L. Shantz [1]

THE PLANT COVER, if properly interpreted, can be used as an indicator of the climatic conditions under which it was produced, of the soils on which it grew, and of the practices of grazing or other use to which it has been subjected. It is of value in the rapid classification of land as to climatic conditions, soil types, soil texture, soil chemical composition, the value of soil for crop production under natural rainfall or under irrigation, the value of the land for grazing with domestic stock or wild animals, and the value for wildlife food production. It may also indicate the amount of overuse to which vegetation has been subjected, the kind of animal responsible for this overuse, and the degree of destruction of the soil profile on which the vegetation is growing.

Plant cover has been used by primitive man as a guide to the choice of the most productive land for crop production, by early settlers in the choice of the best croplands and grazing lands, and, in reconnaissance soil surveys, to note boundaries where soils change from one type to another (figs. 1 and 2). It was used as a rapid means of land classification in classifying lands under the 640-acre homestead law. Observations on crop production or methods of culture at any experiment station can be applied beyond the point at which they have been worked out if the natural vegetation is exactly similar in the new location.

CLOSE RELATIONSHIP BETWEEN PLANTS AND SOILS

As a result of rainfall on the land surface of the earth, a plant cover has developed in physiological and ecological balance with the climatic conditions and the substratum. The interaction of climate and

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FIGURE 1.—The value of vegetation in indicating alkali in the soil. The vegetation at the left is white sage on soil strongly impregnated with salt, that on the right, sagebrush on good land free of harmful amounts of alkali.

vegetation cover modified the surface earth materials, and this surface developed a structure and composition which has been recognized in soil science as the soil profile. Like the great belts of soil series, the great world-wide plant communities are distributed in large zones. Since soil series are the result of interaction of climate and vegetation, plant communities are often closely correlated with the developed soil and often quite independent of the parent material from which the soil was originally formed.

The vegetation cover of the earth's surface made possible a varied animal population, adapted in every particular to this basic food supply. Man has depended in large part on the natural plant cover to furnish his food, building materials, and clothing, and to supply feed for game animals, fish, and flocks of domestic animals. Even today the grasslands and forests, little modified, furnish man a great proportion of his timber, wool, and meat, as well as hides and skins. This natural land use is being increasingly recognized as an important part of any land-use program from the standpoint of a long-time security.

In the classification of soils, only soil characteristics should be considered, and in the classification of vegetation, only characteristics strictly limited to vegetation. These independent groupings can then

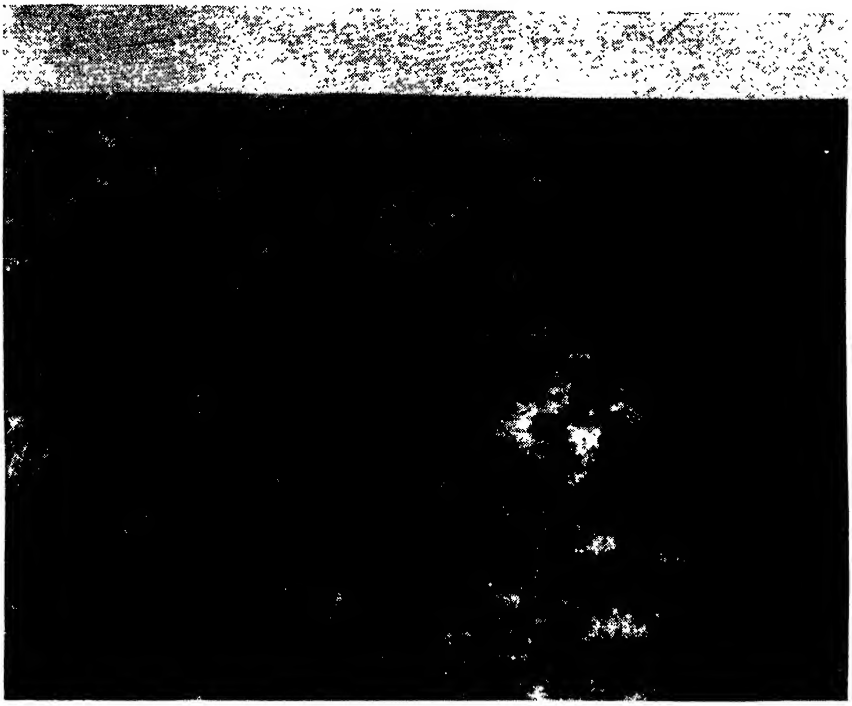


FIGURE 2.—The effect of plowing and a disturbed surface of soil on plant cover. At the right, typical short grass (blue grama and buffalo grass). At the left, wire grass (red three-awn), which has come in as a result of breaking about 10 years before.

be compared. Plant communities can be correlated with soil series, climatic provinces, and agricultural regions.

Ecology studies the relation of a plant to its environment, as well as the morphology and physiology of the plant, but it is also interested in mass vegetation or, in other words, in plants grouped together into communities. These plant communities have been studied and classified into a more or less elaborate system. The groups are designated as formations, associations, societies, etc. It is necessary to recognize in vegetation the essential features that define a plant association or a plant formation, just as it is necessary in soils to recognize the properties that define a soil type or a soil series.

The great plant communities (formations and associations) are relatively independent of such factors as physical composition of the soil, while the smaller or minor communities are often directly affected by such factors. Soil provinces are relatively independent of such factors as physical composition of the parent material, but the soil types are often affected by this factor. In other words, soil units are closely associated with small vegetation communities (societies) and soil provinces with great communities (formations or associations).

While the correlation of plant communities and soil series or types may be relatively exact, there are basic differences between soil de-

velopment and plant successions. Climate does not affect any two plants in exactly the same way, nor does it affect sand and clay in exactly the same degree. The plants are adjusted rather exactly to temperature, moisture, and even light conditions. The same is true, but in a somewhat different sense, of soils. Examples of a few of these differences will explain the lack of exact overlapping of plant communities and soil provinces or soil series.

In general, sandy soils more rapidly develop into a mature soil than loams and clays, since leaching is more easily effected. With plant communities, however, the sands are usually occupied with the earlier or less fully developed stages of plant succession. Sand is also an equalizer when the physiological conditions of soil moisture that affect the plant are considered. In a region of heavy rainfall, drainage in sand is so rapid that the plant is left in a moist soil with plenty of aeration. In regions of little rainfall the scant moisture supply passes rapidly into the soil which, because of low water-holding capacity, allows it to penetrate much deeper than in a heavier soil, and this moisture is protected from evaporation loss by the sand layer above. The soil moisture under both conditions is almost identical. Therefore, eastern (humid) species push far into the semidesert country on sandy lands, and the semidesert types far into the humid country on sand. The effect of the climatic conditions on soil development in the two areas is distinctly different, however, since leaching is proportionate to rainfall, and in addition, in the semidesert country, sand shifts about because it is less securely held in place by a plant cover.

Another factor, rainfall, translated into soil moisture, affects soils and vegetation in a somewhat different way. In North Dakota a ton of alfalfa can be produced with 500 tons of water, while on the Panhandle of Texas 1,000 tons would be required. Small grains generally require twice as much water in Texas to produce a ton of dry matter as in North Dakota. From the standpoint of soil development, however, the higher temperature in Texas, which is partly the cause of higher water use by plants, increases the solvent action of water, which tends to produce a greater reaction on the soil and thus hastens profile development. In Texas, conditions of soil moisture equal to those in Dakota from the standpoint of plant growth should have nearly twice the effectiveness in leaching the soil and increasing the depth to the carbonate layer. The observed correlation of vegetative communities on the High Plains is explained by these considerations. The Chernozem belt lies more wholly within the tall-grass and wire-grass belts in Nebraska and Kansas, but swings west in Texas until more than half its width is in short-grass vegetation. Soil provinces swing farther to the west or drier side in the South while plants swing farther to the west or dry side in the North. This lack of an exact correlation is inherent and affords a very interesting and valuable point of attack on both soil and vegetation problems.

If the map of the vegetation (fig. 3) and the soil map at the end of the Yearbook are compared, it is evident that, although the maps were drawn independently with no attempt to reconcile boundaries, there is a striking similarity.

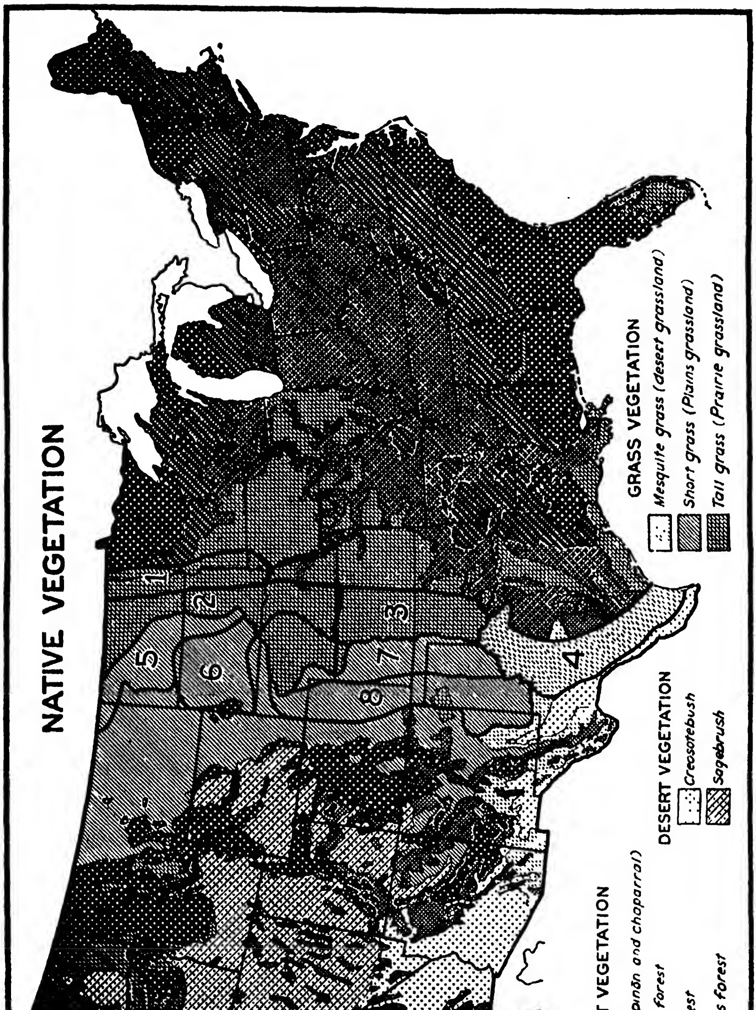


FIGURE 3.—Types of native vegetation of the United States. In addition to the legend on the map the following plant communities are designated by number: (1) Porcupine grass, junegrass, and slender wheatgrass; (2) needle-and-thread, junegrass, and slender wheatgrass; (3) little bluejoint (bunchgrass); (4) desert grass savanna; (5) blue grama, junegrass, and needle-and-thread; (6) blue grama, buffalo grass, and bluestem (western wheatgrass); (7) blue grama, buffalo grass, and red three-awn (wire grass); (8) blue grama and buffalo grass.

On a broad basis the deciduous and coniferous forests and the prairie grasslands occur on soils of the Pedalfer group (*354*).[2] Here water passes continually through the soil to the water table, the soils are moist during most of the year, and the subsoil is permanently moist. The true prairie, the Plains and desert grasslands, and the northern and southern snrub deserts are limited to the Pedocals. Here the rainfall is not sufficient to furnish the surface soils with

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

more moisture than is utilized by the vegetation. The subsoils are permanently dry and mineral matter is not lost beyond the reach of the roots as is the case in the Pedalfers. Drought is always a factor and the growing season is usually shortened materially by lack of available soil water. These soils are rich in mineral matter. Where a water table comes near enough to the soil surface to enable water to rise to the surface by capillarity, salts are left behind by the evaporation of water, and the area is changed into a salt desert. Black alkali (carbonate of soda) and white alkali (sodium and magnesium sulphates and chlorides) are characteristic of the moist soils of the greasewood or salt-desert shrub areas of the West.

VEGETATION TYPES AS INDICATORS OF SOIL SERIES

Spruce-Fir (Northern Coniferous Forest)

This forest is found in the East in northern New England, New York, the higher portion of the Alleghenies, and the northern portion of the Lakes States, and in the West in the higher Cascades, Sierras, and northern and southern Rockies. In the West and on the Alleghenies it is found at high elevations, but in New England and the Lakes States it is characteristic of low, flat, acid lands. The eastern forest is chiefly red and black spruce, balsam fir, tamarack, and white cedar. There is often too little light at the forest floor for a ground cover to develop, but when it does it is usually of ericaceous and other plants which thrive in an acid, raw, humous soil. The biological characteristics of the various spruce-fir areas are similar.

Such observations as have been made in the West and studies in the East indicate a Podzol soil or raw material that is gradually being developed into a Podzol profile under the spruce-fir forest. Characteristic soils include Hermon, areas of peat and muck, Beltrami, Ontonagon, Dekalb, and Summerville. (For descriptions of the soil series, see Soils of the United States, p. 1019.)

White, Red, and Jack Pines (Northeastern Pine Forest)

This forest is confined largely to the Lakes States. White pine is scattered with hardwoods in New England and in New York, and white pine and eastern hemlock in the Alleghenies. The most extensive forest of white pine was on the sandy soils of Michigan. Jack pine is confined to the poorer sandy soils. Red pine occurred for the most part on light soils, while white pine occupied the better, or relatively heavier soils, or was mixed with the hardwoods.

Except for a few areas of good soils, this forest occupies land that has failed for agricultural use. It lies in the hay and dairying agricultural region (*21*), but the areas formerly occupied by the forest are marked out as nonproductive even on maps showing hay production. These areas were, however, of great value for forest production. Bad management has resulted in loss of the original stands and, with repeated fires, all or nearly all of the surface humus. To bring about a return to productivity may take many years.

In places this pine forest marks a true Podzol such as the Hermon, but more often it is not fully developed. Even as far south as New Jersey the sands occupied by pitch and shortleaf pine are Podzolic in structure. Hermon, Dekalb, and Beltrami, especially the lighter, more nearly Podzol types, are indicated by the northeastern pine forests. In the Alleghenies of Pennsylvania, great forests of white pine and hemlock also occurred on Podzolic soils of Dekalb-Leetonia and similar types.

Birch, Beech, Maple, or Hemlock (Northeastern Hardwoods)

This forest varies considerably in composition. Great hardwoods such as sugar maple, beech, and yellow birch, with a forest floor of dogwood, blueberry, and ericaceous plants, ferns, and mosses, beech forests, and beech-maple forests have

largely disappeared to make room for the hay and dairying region of the United States. This forest is typical of the Lakes States, New England, and New York, and is also found in favorable locations in the Alleghenies as far south as Georgia. The soils under the forest are podzolic, including the less fully developed, such as Caribou and Dekalb, and the Gray-Brown Podzolic soils, such as Gloucester, Lordstown, Volusia, Muskingum, and Superior.

Oak (Southern Hardwood Forest)

The larger part of the eastern deciduous forest is characterized by oak, of which there are many species. This forest differs from the beech, birch, and maple in that it is less likely to be characterized by an ericaceous ground cover and is not as a rule so cool and dark. For the most part, the area corresponds to that of the Gray-Brown Podzolic soils. In the Southeast, if the oak-pine type is excluded, the forest and soil province boundaries are fairly close. The oak forest may be divided into three large subdivisions.

Chestnut, Chestnut Oak, and Yellow Poplar

This forest, one of the most extensive and especially interesting, has lost its principal member, the chestnut, as a result of disease and would now be more properly known as the chestnut-oak and yellow poplar forest. It extends from southern New England, New York, and Pennsylvania south on both sides of the Alleghenies across North Carolina and Tennessee and into northern Mississippi, Alabama, and Georgia. It includes a greater number of important species than are found in any other American forest.

This forest has given way to farm land over large areas and its soils have been mapped and studied to a greater degree than the northern coniferous and hardwood forest lands. It lies largely in the Gray-Brown Podzolic soil region and includes the northern part of the Red and Yellow Podzolic soils. A large number of soils are included, but all are similar in character. Among the more important are the Chester soils of the Piedmont of Virginia, Maryland, Pennsylvania, and New Jersey; the Gloucester farther north; the Hagerstown and Fredericksburg of southeastern Pennsylvania, Maryland, Virginia, Kentucky, Tennessee, and southern Indiana; the Muskingum southwest to Alabama; the Ontario-Honeoye of New York; the Upshur-Muskingum of eastern Ohio and western Pennsylvania; the Westmoreland of western Pennsylvania; and the Welston, Zanesville, Lowell, Dickson, and Baxter of Kentucky.

This forest area, once important as a source of timber and forest products, has given way in large part to a dense agricultural population.

Oak-Hickory

This was the western extension of the oak forest, the type that pushed up along the flood plains of the rivers draining the Great Plains and the great prairies and out onto the level lands, where possible in the face of competition by grass and fire. The chestnut oak, chestnut, and yellow poplar give way to oaks, hickories, ash, elm, walnut, and boxelder. If a detailed map could be drawn, it would show great diversity in Michigan, Ohio, and Indiana, and there is a great difference between the southern oak-hickory and the most northern extension of the type in northern Minnesota. This forest area dovetails into the prairie, from which it differs, not in environmental conditions, but in original vegetation and consequent soil. The soils developed under the two covers are distinct except where recent recessions have established grasslands on the Gray-Brown Podzolic soils, which are light in color as compared with the soils of the northern and southern prairie, or where trees have recently pushed out onto the dark Prairie soils.

In this forest area the typical Gray-Brown Podzolic profile is shown in the Miami-Kewaunee soils of Ohio, Indiana, southern Michigan, and southeastern Wisconsin; the Baxter on the more level areas over limestone in the Ozarks of Missouri; the Clinton and Lindley soils along the rivers of Missouri, Illinois, Iowa, and adjacent States. The forest area abuts closely on the prairie. The Cross Timbers of Texas are found on Windthorst-Nimrod Red and Yellow Podzolic soils. The oak-hickory in its northern extension has developed into parts of the

hay and dairy region; in the central section in Ohio and Indiana into the Corn Belt; in southern Illinois and Missouri into the Corn and Winter Wheat Belts; and in the extreme south into the Cotton Belt.

Oak-Pine

This forest is probably not a true climax forest. Grouped with the oak forests by Shantz and Zon (*354*), the soils on which it occurs have been mapped by Marbut (*240*) as Red and Yellow Podzolic soils, which are characteristic of land occupied by the southeastern pine forests. The original forest was largely cleared for farm lands. Shortleaf is the principal pine, although scrub pine is prominent in parts of Virginia and North Carolina, especially on poorer soils and old fields, indicating that it occupies a prominent place in the earlier stages which lead to a climax forest. Better soils are occupied by loblolly. In the North, red, yellow, and chestnut oaks are prominent, while the pines, hickory, and oak are more prominent in the South. West of the Mississippi, shortleaf pine, yellow oak, bitternut and pignut hickories, blackjack oak, and mockernut hickory were prominent in the original forest. Much of this oak-pine forest is reestablishing itself on abandoned farm lands and now presents many earlier successional stages in progressing toward the climax forest.

Soils of importance are the Sassafras soils in the North, which belong to the Gray-Brown Podzolic group; the Cecil and the associated Appling, Georgeville, Alamance, Iredell, and Louisa, Red and Yellow Podzolic soils of the Piedmont, from Virginia to Georgia and Alabama; the Susquehanna and Hanceville-Conway of Arkansas and the Ozark Plateau, and the Norfolk-Ruston, in Texas.

Except for the northern portion, which lies in the Corn and Winter Wheat Belts, the oak-pine forest has become part of the Cotton Belt, occupied by farms throughout. The number of farms is large and they are relatively small in size with a relatively dense white farm population.

Cypress, Tupelo Gum, and Red Gum (River-Bottom Forests)

This is a mixed forest varying in character with the amount of standing water on the soil or the nearness of the water table to the surface of the soil. Cypress and tupelo gum are swamp trees occupying the sloughs and swamps, which are under water most of the year. The overflowed glades contain, besides cypress and tupelo gum, water ash, cottonwood, and sweet and red bays, and the ridges produce oaks, hickories, gum, ash, and red maple.

The soils are composed of materials flooded in from the highland near the headwaters and are grouped as alluvial soils of the southern United States. Along the river bottom east of the Mississippi, the Ochlockonee in Mississippi and western Alabama and the Congaree farther east were occupied by this type of forest. The great Mississippi flood plain is mostly Sharkey, Sarpy, and Yazoo soils, and the Arkansas and Red River bottoms are soils of the Miller series.

This forest area lies in the humid high-temperature region. The northern part is an area of large cotton acreage and concentrated colored tenant farmers and croppers.

Longleaf, Loblolly, and Slash Pine (Southern Pine Forest)

This pine forest area extends in a broad belt from 1 to nearly 300 miles wide along the Atlantic Ocean and the Gulf of Mexico from North Carolina to eastern Texas, including practically all of Florida except the marsh, prairie, and river-bottom areas. About 10 species of pine are important, with longleaf most prominent on the better drained lands and loblolly on the lower lands. There are great open stands of pine which because of the long, favorable growing season produce timber more rapidly than any other forest in the United States.

The older part of the Cotton Belt lies mostly in this forest. The chief soils are of the Norfolk series. Others are the Orangeburg, Coxville, and Leon; the Tifton in Georgia; and the Ruston and Susquehanna in Alabama, Mississippi, Louisiana, Texas, and Arkansas. These are almost entirely Red and Yellow Podzolic soils.

A great deal of this pine forest is in a raw-land state, in process of reestablishing the original timber type. The best lands are still held in cultivation, principally of cotton. As a general rule these pinelands are not highly productive.

Tall Grass (Prairie Grassland)

The western portion of the oak forest gives way to a tall-grass region, generally called a prairie. Here, owing to fire and, at times, a high water table, trees have been unable to establish themselves, although the conditions of soil and climate would favor their growth. A constantly maintained coarse grass and herb vegetation burned off each year, or at irregular intervals, has developed a soil out of keeping with the Gray-Brown Podzolic soils of the oak forests, or the Red and Yellow soils of the southern extension. Here are grasslands similar to those found on the Chernozems, but the lime layer is not present because of high rainfall. From the standpoint of plant geography and soil geography it is exceptional, and no similar extensive areas are found on other continents.

Something of the richness of the Chernozems combined with the adequate water supply indicated by the podzolic soils gives this area great significance as agricultural land. Grain crops can be grown year after year without fertilizer. It therefore constitutes one of the most valuable blocks of agricultural land found on any continent on the earth. The tall-grass area presents a phase that has developed along the eastern shelf of the Pedocals, where the vegetation is so nearly in balance with the total moisture supply that none of the soil water is lost to the subsoil, which is permanently dry. A layer of lime accumulation is deposited at or near the limit of depth of moisture and root penetration. Just east of this line the soils are Pedalfers, since here water passes below the reach of the grass roots and the subsoil is permanently moist. The grassland east of this dividing line is characterized by the bluestem-sod type of tall grass in the north and the bluestem-sod and the broomsedge-water grass type in the south.

The soils, like the vegetation, are different from those ordinarily characteristic of grasslands in Europe and Asia. The soils of this type in most continents are tree-covered, and forest plantings by Professor Burrell at the University of Illinois show that they quickly return to a forest soil profile here.

Although the soils must be classed as Pedalfers, they are not well developed, and they show characteristics usually associated with the Pedocals. The vegetation is a luxuriant grassland, but the conditions are favorable for the development of the western extension of the oak-hickory forests.

Bluejoint Sod (*Northern Part*)

This great grassland, known to the early explorers as the prairie, was made up for the most part of tall, coarse grasses such as bluejoint, little bluejoint, and Indian grass, with a rich admixture of flowering herbs and other grasses. A mass of flowers in the spring and summer, it changes to a rich reddish-brown color in the fall.

The plant cover of this bluejoint sod marks a soil type with characteristics of both the Podzol and the Chernozem great soil groups. It is correlated with the Carrington, Clarion, Tama, Marshall, Summit, and Cherokee soils. The Carrington and Clarion soils, important in the northern portion, with the northern portion of the Marshall, are considered typical Prairie soils. In eastern Kansas and western Missouri, Summit, Grundy, Shelby, Cherokee, Bates, Crawford, and Parsons are important. They are less typical prairie soils because of the nature of the shales and materials from which they were derived.

The northern part of the bluejoint-sod grassland lies in the Corn Belt and the southern part in the corn and winter wheat region.

Bluejoint Sod (*Southern Part*)

This grassland is characterized by the soils of the southern prairie. The vegetation is not decidedly different from that of the northern prairie except for a number of grasses, such as the broomsedges, from the south. The climatic conditions are less severe than in the northern prairie.

The Houston, Austin, and Wilson soils are associated with the Black Prairie of Texas, and the Sumter, Vaiden, and Wilson with the prairie region of Alabama and Mississippi. This grassland lies wholly in the Cotton Belt.

Broomsedge and Water Grass

A strip of prairie grassland lies along the Gulf of Mexico in Texas and Louisiana and constitutes small prairies in Florida. *Andropogon*, *Paspalum*, and other coarse grasses predominate. Because of the long growing season, parts of this belt resemble the Plains, and the short grasses push in in many places.

The soils are dark-colored because of the parent material and are classified as Lake Charles. This area lies wholly in the humid subtropical agricultural belt.

Porcupine Grass, Junegrass, and Slender Wheatgrass

This grassland, which occupies the Red River Valley of North Dakota and Minnesota, lies north of the bluejoint sod and east of the needle-and-thread, junegrass, and slender wheatgrass area. From the latter it differs chiefly in greater abundance of porcupine grass and a somewhat larger growth.

This plant community occupies the eastern edge of the spring wheat region and produces, also, a large amount of native hay. The soil occupies the eastern edge of the true Chernozems represented by the Fargo-Bearden soils.

Needle-and-Thread, Junegrass, and Slender Wheatgrass

This grassland extends from northern North Dakota south to southern Nebraska and lies wholly within the Chernozem soil province. It is characterized by the grasses named and a luxuriant mixture of other plants. It merges almost imperceptibly into the porcupine grass, junegrass, and slender wheatgrass on the east and the more luxuriant phase (called by Clements (*69*) the "midgrass") of the short grass or plains grassland on the west.

The subsoil is permanently dry or at least contains no water available to growing plants (*352*). The growth period is shortened by summer and autumn drought, although the frost-free period is from 100 to 170 days. The evaporation from a water surface amounts to 30 to 40 inches. Summer temperatures average 60° to 75° F., winter temperatures 5° to 30°. The temperature range is from −60° to 115°.

The plant community marks the eastern edge of the Pedocals in the north and falls near the midline of the true Chernozems or northern Chernozems. It is characterized in the Dakotas by the Barnes soils, and on somewhat more open or rocky soil by the Bearden. The correlation between these soils and the grassland community is almost exact. In Nebraska the vegetation is correlated with the Moody soils. This grassland marks out very sharply the spring wheat area in the north and the Corn Belt in the south, but also produces barley, rye, and flax.

Little Bluejoint-Bunchgrass (Bluestem-Bunchgrass)

This grassland (*352*) occupies a belt about 100 miles wide running from north to south across the middle of Kansas, swinging west to the eastern edge of the Panhandle of Texas, and extending across Oklahoma. One grass is dominant over much of the area. In the fall this stands as a dense, almost grainlike field of rich reddish-brown color. The grasses are closely placed bunches and have less of a sod character than they do farther east.

The northern portion of the bluestem-bunchgrass lies in the Corn Belt, the center in the Winter Wheat Belt, and the southern portion in the Cotton Belt. It is an area of high productive capacity.

The soils that characterize the bunchgrass vegetation are Chernozems such as the Holdredge, Hall, Crete, and Colby soils in Nebraska, the Hays and Crete soils in Kansas, and in southern Kansas and Oklahoma the Reddish Chestnut soils such as the Miles, Vernon, Greensburg, Pullman, and Richfield.

Sandgrass, Sand Sage, and Shinnery Oak

A mixture of bluejoint, Indian grass, switchgrass, sandgrass, and sand sage, and in the south the shinnery oak, marks areas of sand valuable only for moderate grazing and for the production of native hay. This type has been mapped in soil maps only as sand. It is never found on heavy land.

Short Grass (Plains Grassland)

This great belt of grassland lies between the prairies of the Central States and the Rocky Mountains. Naturally the line of demarcation where there is no physiographic boundary is not distinct. The boundary which separates the Pedalfers from the Pedocals falls farther east at the eastern boundary of the needle-and-thread, junegrass, and slender wheatgrass, and the little bluejoint-bunchgrass associations. The western edge of the Chernozem belt falls within the boundary of the blue grama, junegrass, and needle-and-thread association in the north, and west of the wire-grass association in the middle Plains section. But the line drawn between the tall grass and the short grass represents a very marked change from a darker to a lighter Chernozem and is distinctly indicated in dot maps of crop production, land in farms, and size of farms.

These two eastern associations of the short-grass or Plains grasslands are often referred to as midgrasses (*69*) or as mixed prairie, and since many of the taller grasses continue across to the mountains, the whole area is referred to as the mixed prairie. During dry years the taller grasses are not in evidence, but during wet years they are much in evidence. There is a tendency for the tall grasses to push west on lighter soils and for the short grasses to push east on heavier ones.

The communities comprising the Plains grassland may be grouped into the following six associations:

Blue Grama, Junegrass, and Needle-and-Thread

This vegetation occupies most of western North Dakota and north-central South Dakota north of the areas of the Pierre shales and also some of the better soils of eastern Montana (fig. 4). It consists of a short cover of blue grama with

FIGURE 4.—Overgrazed short-grass land in Montana, showing pasture sagebrush replacing the grasses.

needle-and-thread and junegrass, and a scattering of many herbaceous plants such as silver *Psoralea* and purple coneflower.

This grassland occupies the northwestern part of the Chestnut soils in the belt of the Williams-Morton-Bainville series. The area lies in the spring wheat region.

Wire Grass

This is an intermediate type lying mostly between the little bluejoint-bunchgrass of the central High Plains and the grama-buffalo grass of the west-central High Plains. It consists of a ground cover of blue grama and buffalo grass and a scattered growth of red three-awn (wire grass) with coneflowers, *Psoralea,* and many other herbaceous plants.

The eastern portion of the northern extension of this association is correlated with Chestnut soils of the Rosebud, Bridgeport, and Keith series. The western edge covers northern Brown soils such as the Rosebud and the Daws, and the southern portion Reddish-Chestnut soils such as the Zita, Pullman, and Greensburg. The wire-grass vegetation marks the western part of the hard winter wheat region.

Grama-Buffalo Grass

The most typical part of the west-central High Plains is the short-grass cover on hard land. Beginning growth in the spring as soon as the temperature is favorable, the grasses fruit in 40 to 60 days but are often caught by drought before maturity of the seed crop. Before the flower spikes are pushed up, the appearance at a distance is that of a well-kept lawn. During periods of drought it forms a dry carpetlike mat of gray or lemon-yellow color. The grama heads, with a mixture of other taller plants such as *Psoralea* and other legumes and many showy flowering plants and taller grasses, give the area an appearance of a more varied composition. This is especially noticeable during wet years.

In the north, grama and buffalo grass (fig. 5) occur on Chestnut soils of the Rosebud series. On the western side they occupy the eastern extension of the Weld series of the Brown soils. In southeastern Colorado they occur on soils of the Baca and Prowers series. In the southern Plains they occupy the eastern part of the Springer series of the southern dark-brown soils and the western portion of the Amarillo, Zita, and Pullman soils.

This association marks the western edge of the hard winter wheat region.

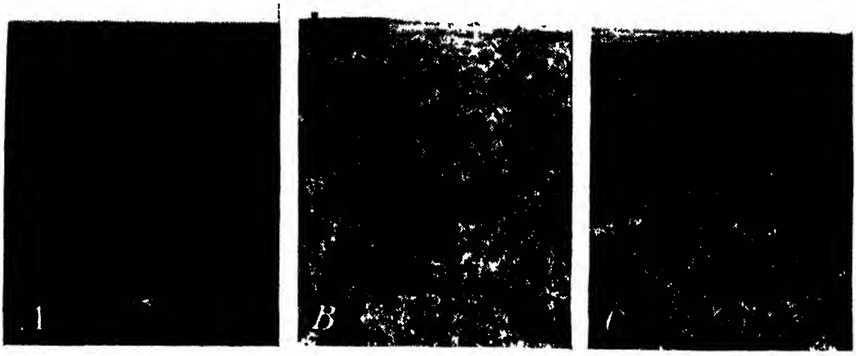


FIGURE 5.—The vegetation under like climatic conditions indicates the soil texture: *A*, A loam soil under blue grama and buffalo grass; *B*, a sandy soil under wire grass; *C*, little bluejoint on sand.

Blue Grama, Buffalo Grass, and Bluestem

On heavy soils derived from the Pierre shales the bluestem (western wheat-grass) forms an even stand on a blue grama and buffalo grass sod. During dry years the cover is similar to the grama-buffalo grass association, but when moisture is available the appearance is almost like a field of small grain.

Although bluestem is found scattered through much of the short-grass area, in no case does it become as prominent as in this association. Here it is correlated closely with the Chestnut soils of the Pierre series (fig. 6, *A*).

This association lies in the southwestern part of the spring wheat region.

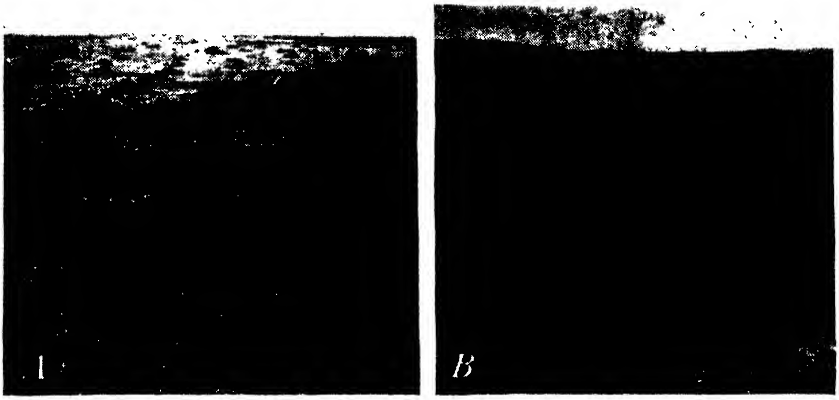


FIGURE 6.—*A*, Blue grama, buffalo grass, and bluestem on good Pierre soils; *B*, bluestem alone on undeveloped soils with enough alkali to shut out the short grasses.

Bluestem (Alone or With Sagebrush or Salt Sage)

This association (fig. 6, *B*) is found in the badlands areas and on heavy soils along the rivers of Montana, Wyoming, and South Dakota. The plant cover is rather open and varied and distinguished by the absence of short grass. Bluestem may occur as widely spaced plants or with poor sagebrush, and on saline soil with salt sage.

The association occurs on heavy, impervious, saline soils of little value except as grazing land of low carrying capacity. For the most part these are undeveloped Brown and Chestnut soils such as the Pierre and Bainville, and badlands types.

Blue Grama Grass

This area is occupied by blue grama in combination with "niggerwool," junegrass, selaginella, pasture sagebrush, and sagebrush. Each of these combinations indicates a different type of soil and also varying conditions favorable for grazing or crop production. The group covers most of the northwestern part of the Plains grassland.

Blue Grama and Niggerwool

This grassland is a little drier and covers the soil less completely than the blue grama, junegrass, and needle-and-thread. It is characteristic of much of the better soil of the northern and western portion of the Great Plains. In the south it extends to about central Colorado. Semidesert in character, it forms an open cover and is characterized by a large number of other grasses and herbaceous plants.

In the north this association occupies Chestnut soils such as the Williams, Scoby, and Morton. Further south in Colorado it is found on Brown soils such as the Joplin and the Weld. In New Mexico and Arizona it occurs on Brown soils

of the Capulin and Tucumcari series. It also occurs in some of the parks of the intermountain country and over the higher grasslands of New Mexico and Arizona as blue grama and galleta on the Otero soils.

Blue Grama, Junegrass, and Selaginella

An area sharply marked out in northern Montana is covered with short grass with a good deal of selaginella, phlox, and other small xerophytic species. This type is scattered throughout the range of the blue grama and niggerwool association, but is not easily segregated on a map. Conditions are rather extreme, but the change in vegetation is marked more by amount of growth than by change of botanical composition. As grazing land it will carry from 15 to 20 head of stock per square mile.

This area is correlated with Brown soils of the Joplin series, surrounded on all sides by Chestnut soils.

Blue Grama and Pasture Sagebrush

This name is an inadequate description of that portion of the Plains grassland which on the west meets the Pacific bunchgrass with its attendant *Balsamorhiza*, and the bunchgrass-wheatgrass and the extensions of pine forests. Naturally, with an increase of rainfall, the vegetation becomes denser and taller. More of the herbaceous plants such as goldenrods, asters, legumes, lilies, as well as needle-and-thread and other grasses, enter. The soils are darker and deeper. The vegetation type is an extension from the north characteristic of the mountain front. It is also found on certain open sandy and rocky soils in North Dakota. In places the land has been cultivated, but as a rule it is pasture varying in carrying capacity from 20 to 30 head per section. Not much of the area has received detailed attention in soil surveys, but its characteristic soils are of the northern dark-brown or the Chernozem groups.

Blue Grama and Ring Muhly

This combination occupies the driest and hottest portion of the Plains grasslands. It is characterized either by the "fairy ring" growth of the *Muhlenbergia*, which has led to a proposed common name "ring muhly," or this plant may occur in almost equally distributed tufts. This plant, seldom seen north of central Colorado, is mixed with blue grama, and often cane cactus grows as scattered bushes over the grass cover. As a rule the soils are heavy and the vegetation for the most part occupies the low and level lands.

In Colorado and New Mexico this association occurs on Brown soils of Capulin and Tucumcari type. The value of this land is chiefly for light grazing. Care should be exercised, since erosion is likely to start if the vegetation cover is disturbed.

Mesquite-Desert Grass Savanna (Desert Savanna)

A scattered growth of mesquite over a desert-grass cover occupies a curved belt of land across Texas from the Red River on the north to the Gulf of Mexico. It is interrupted slightly by the Edwards Plateau. The vegetation differs from that of the Plains grassland in that trees are scattered over a short-grass cover. The growing season is not determined by suitable temperature but almost entirely by the time when moisture is available in the soil. Growth starts following spring or summer rains.

This desert savanna is divided into two major associations.

Thornbush and Mesquite Grass

Mesquite and other thornbushes and cacti are scattered over a desert grass cover consisting of curly-mesquite, buffalo grass, and three-awn grasses. This plant association occurs on Reddish Chestnut soils of the Miles, Vernon St. Paul, Abilene, Valera, Ector, Duval, Victoria, and Webb series.

Mesquite and Mesquite Grass

A thin belt of curly-mesquite and buffalo grass with a scattered growth of mesquite extends from south of the Panhandle of Texas in a narrow curved belt to the Gulf of Mexico. It lies just west of the thornbush and mesquite grass association. In its northern extension, it occupies Reddish Chestnut soils, but the southern and western portions pass over onto southern Brown soils.

Climatic conditions are a little more arid than in the thornbush and mesquite grass association. In the north it occupies soils such as the Vernon and Amarillo. At about 32° N. latitude this vegetation occupies Reddish Chestnut and Reddish Brown soils such as Springer, Reagan, and, farther south, Maverick, Duval, and Victoria.

Mesquite Grass (Desert Grassland)

This grassland resembles the short-grass areas of the High Plains, especially where curly mesquite is relatively dominant. The vegetation is distinct from the short grasses in habitat and physiological adjustment. Growth starts as soon as rain falls. This vegetation occurs in Texas, New Mexico, and Arizona on Reddish Brown soils such as the Whitehouse, Tumacacori, and Coronado. It is fairly good grazing land, supporting 20 to 30 head of cattle per section.

Curly-mesquite, with black, Rothrock, and sprucetop gramas, are probably most important on the uplands and constitute most of the desert grasslands in southern Arizona (*280*), southern New Mexico, and western Texas.

Bunchgrass (Pacific Grassland)

This grassland occurred in California, Oregon, and Washington and in the mountains of Idaho, Nevada, and Montana.

It has been divided into three associations.

Wheatgrass Sod

This grassland of bluebunch wheatgrass, Idaho fescue, and an admixture of balsamroot is limited largely to the Palouse section of Washington and adjacent portions of Idaho and Oregon. Both the soils and the vegetation are similar to those of the northern Great Plains. The soil is classified as Palouse. This vegetation unit marks the best wheat lands of the Northwest.

Wheatgrass Bunch

This open grassland made up of distinct bunches of bluebunch wheatgrass and a rich admixture of other plants occurs where moisture is not as abundant as on the sod and where the soils are not so good. It is found in eastern Washington and Oregon and in Idaho, Montana, and northern Nevada, where it occupies the zone above the sagebrush desert.

The topography is hilly and not favorable to cultivation, but much of the area is farmed to wheat. The community characterizes the Brown Ritzville and the Chestnut Walla Walla soils.

Stipa-Poa Bunchgrass

The original vegetation has largely disappeared from the California grasslands. This was a luxuriant bunchgrass land of pine bluegrass and California needlegrass, probably as rich a mixture as found on the bunchgrass land of the north.

The former grasslands were usually noncalcic Brown soils such as the Placentia and Ramona, which lie on the benches at the side of the valleys; the Yolo alluvial soils; and in places, the San Joaquin and the Fresno, the latter sometimes passing over to salt-desert shrub.

This *Stipa-Poa* bunchgrass has given way to a weed grass cover of wild oats, bromes, and tarweeds. Under cultivation it is productive of cereals grown for grain and hay, and under irrigation for subtropical fruits and vegetables.

59183°—38——55

Sagebrush (Northern Desert Shrub)

Sagebrush is the most prominent plant of this association and has been used to designate the whole area. The plants are usually 3 or more feet apart and from 2 to 7 feet high. At times they present the appearance of a miniature forest. The soil surface, originally partially covered with grasses and native herbaceous plants, is now often covered after rains with bromes, filaree, and Russian-thistle. The area occupies the Great Basin, the Harney Plateau, the valley of the Snake River, central Washington, western Colorado, and Utah.

The soils are largely alluvial materials deposited as alluvial fans. This results in soils in all stages of development on each fan and also all stages of vegetation

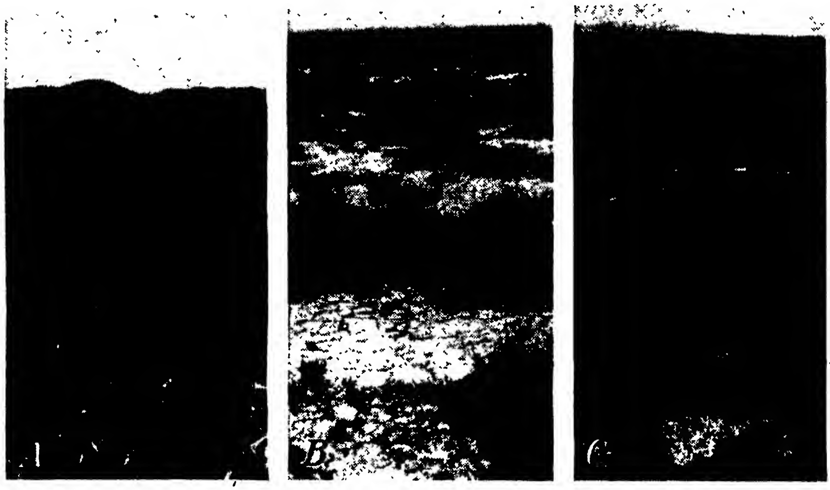


FIGURE 7.—Under the same climatic conditions vegetation indicates differences in salt content of soil: *A*, Sagebrush on soil free from harmful amounts of alkali; *B*, shadscale on soil of moderate salinity; *C*, salt sage on strongly saline soil.

development. The association occupies the Gray Desert soils typical of Nevada, southeastern Oregon, Washington, southern Idaho, Wyoming, and Colorado of which the Portneuf, Sagemoor, and Navajo-Chipeta soils are types.

The northern desert shrub can be broken into many types, each definitely correlated with soil conditions. The principal plant communities and what they indicate as to soil conditions are as follows.

Sagebrush indicates a pervious soil moistened to a depth of several feet and free from alkali (fig. 7, *A*). This is good agricultural land under irrigation and is successfully dry-farmed during average or better-than-average years.

Small sage indicates a shallow and often impervious soil. Such land, although not high in alkali, is nonagricultural.

Scabland sage indicates the absence of sufficient soil to produce sagebrush.

Little rabbitbrush grows in Utah and Nevada on soils similar to sagebrush lands but drier and less valuable for crop production. They are free from harmful amounts of salts and often mark areas where sagebrush has been driven out by drought or burning.

Bitterbrush is usually on sandy, volcanic, or rocky soil.

Coleogyne, occurring at the southern boundary of the northern desert shrub and the northern boundary of the southern desert shrub, occupies soils that are loose, rocky, or sandy.

Chamiso generally indicates sandy land in both the northern and southern desert shrub.

Shadscale dominates the more level and mature soils of the whole sagebrush desert (fig. 7, *B*). Rainfall is less than on sagebrush land. The soils are of fine

texture, with harmful amounts of alkali at a depth of 1 to 2 feet, and poorly supplied with water owing partly to poor penetration.

Salt sage, as a low mat cover with much of the surface bare, occupies soils that are heavy and highly saline even at the surface (fig. 7, *C*).

White sage, sometimes with accompanying Sandberg bluegrass, indicates a fine ashlike soil with alkali at a depth of 10 inches to 1 foot.

Winterfat as a rule marks land that is suited for crop production without irrigation. Soils vary considerably but are often of fine texture with alkali at a depth of 1 to 2 feet. The land is excellent for grazing.

Galleta occupies soils usually pervious and free of harmful amounts of alkali. Conditions are not unlike those under sagebrush but the soils are probably older and are generally light loam or sand loam in texture. This is good grazing land.

Giant wild-rye characterizes the richer, more moist alluvial bottoms in the sagebrush desert free from alkali. It indicates the best soils and the best conditions of soil moisture in the northern desert shrub.

Creosotebush (Southern Desert Shrub)

This desert is far more varied than the sagebrush desert. The latter as a rule has plants of about equal size and with deciduous silvery leaves. The creosotebush has shiny, lacquered, yellowish-green leaves, and the desert as a whole shows great variety, ranging from the silvery bur-sages, desert sages, and encelias to the green paloverde and mesquite and from thornbush to giant cactus. There are a great number of plants of great variety in habit of growth. The northern desert offers expanses of miles and miles of uniform color and shape, while the southern desert offers endless variety.

In many places the soils under the southern desert shrub form a desert pavement, from which the fine materials have blown away leaving small rock fragments accumulated on the surface. These are polished by wind action and by temperature changes and take on a "desert varnish." This pavement holds the fine material in place and prevents erosion loss by either wind or water. Characteristic of Red Desert soils of California, Nevada, Arizona, New Mexico, and Texas are the Mohave, Reeves, and Anthony.

The various types of southern desert shrub are correlated sharply within any area with the soil type (*353*).

Creosotebush occupies the alluvial fans and like the sagebrush indicates a deep pervious soil free of harmful amounts of alkali. A stony, shallow soil is shown by poor growth of the creosotebush.

Desert saltbush occurring in a dense stand indicates a soil of fine texture containing salt, but not enough to injure cultivated plants if irrigation is such as to prevent further concentration. The character of the soil and the amount of available water is indicated by the density of the stand. As one passes from the better lower lands toward the alluvial fans, the plants stand farther apart. Soon creosotebush or bur-sage plants appear. These mark a transition from a heavy rich loam soil to a pervious sandy or rocky soil. Soils of the Gila and Imperial series, the best agricultural lands of the southern desert, are characterized by desert saltbush.

Mesquite in solid stands indicates a good soil of considerable depth with plenty of available water, and probably a water table or a body of soil water moving slowly through the soil below the trees.

Narrowleaf saltbush indicates a heavy, compact subsoil with a surface layer of lighter soil 4 to 8 inches in depth, a small amount of available water, a small amount of salt in the surface soil, but over 0.5 percent of salt in the compact subsoil.

Giant cactus as a rule is found on soils sufficiently rocky to afford a safe anchorage for the superficial root system.

Chamiso clearly marks the sand ridges in the southern deserts which often lie above a heavy alkali soil.

Sacaton, a tall coarse bunch grass, occupies the best alluvial bottoms in the southwestern desert where, after rains, water floods slowly over the surface and moistens the soil to several feet in depth (fig. 8, *A*). Such land is free of harmful amounts of alkali. The plant indicates the best soil and natural moisture conditions in the southern desert shrub area, just as giant wild-rye does in the northern desert shrub area.

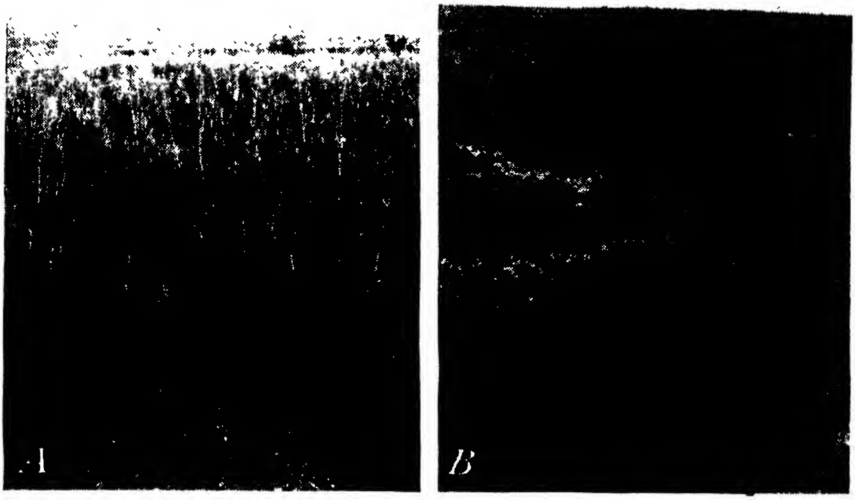


FIGURE 8.—*A*, Sacaton on alkali-free land; *B*, alkali sacaton on moist alkali land.

Greasewood (Salt-Desert Shrub)

In the desert areas of the West, restricted drainage causes salts to accumulate in the soils. In extreme cases these salts crystallize out to form a white deposit; or, where black alkali is present, to produce bare flats that are slick when wet and as hard as concrete when dry, with no plant growth of any kind. Salt-desert vegetation is found along almost every drainage channel in the West. Such plants clearly indicate the soil condition.

Greasewood indicates a subsoil well supplied with water, probably within a few feet of the water table. The soil contains more than 0.5 percent of salt and is not productive under cultivation without leaching.

Greasewood and shadscale indicate a soil with alkali within 1 or 2 feet of the surface. Usually this is a heavy soil and nonagricultural unless it is leached.

Seepweed indicates a water table near the surface or actual seepage of water from the soil on which it grows and a high alkali content often exceeding 2.5 percent in the surface soil.

Pickleweed indicates moisture throughout the growing season from a water table near the surface, and a salt content rarely less than 1 percent and often as high as 1.5 percent.

Samphire indicates moist alkali land.

Saltgrass indicates alkali, usually a little less than 1 percent, and a moist soil. Generally there is a drainage of fresh water onto these lands after rains. The land is valuable for grazing.

Alkali sacaton, one of the most edible grasses of the desert regions, grows in wet alkali bottoms, on heavy land, moist to the surface, and containing about 0.5 percent of alkali (fig. 8, *B*).

Western Forests

These forests lie for the most part on "rough and stony land" which has so far received comparatively little or no attention from soil scientists. The various forests can probably be more nearly correlated with climatic conditions than with soils. But the earth materials must likewise be affected by climate. Ultimately the soils may be known by the forests that grow on them, and which forests are climax forest stages and which forests still occupy young and immature soils may thus be determined. Only a relatively small area of forests in the West has given way to agriculture and it is these lands which have been studied by the Soil Survey Division.

Spruce-fir (Northern Coniferous Forest)

This forest is practically the same as the spruce-fir of the eastern United States, and evidence indicates that like the eastern forest it grows on a true Podzol, or on soil material that is developing in that direction.

This forest is made up of a very interesting series of trees. In the Cascades there are the noble fir and California red fir, and at higher elevations the alpine fir, Lyall larch, and mountain hemlock; in the Sierras, alpine fir and mountain hemlock, pure California red fir, California red fir and white fir, and lodgepole pine. The latter becomes an important tree at high elevations, which in no wise resemble typical lodgepole areas of the northern Rockies. In the northern Rockies, alpine fir and Engelmann spruce are important; in the central Rockies, Engelmann spruce and balsam fir; and in Arizona, Engelmann spruce and cork-bark fir.

This forest would be relatively unproductive for anything but timber, squirrels, grouse, martin, and fisher except that it is broken by great mountain meadows. This alternation should be especially interesting from a soils point of view since conditions in the meadows would develop a Podzol soil except for the grass cover.

Cedar-Hemlock (Northwestern Coniferous Forest)

This is the heaviest forest in the United States and probably in the world. It occupies the northern Rockies, extends from the west slopes of the Cascades to the Pacific in Washington and Oregon, and forms a strip along the coast of California reaching down almost to San Francisco Bay. It can be divided into three major divisions.

Western Larch-Western White Pine

Located in the northern Rockies in Montana, Idaho, and adjacent areas in Washington, this forest is first composed largely of western larch after burning, followed by western white pine, which in turn is followed by western red cedar and hemlock; this is the reason for its classification with cedar and hemlock forests rather than with the ponderosa pine and Douglas fir.

The nature of the soils under this forest can only be inferred. They appear to belong to the Gray-Brown Podzols represented by such soils as the Everett, Alderwood, and Helmer-Santa-Benewah. The soils named have been cleared for agriculture but were formerly heavily timbered.

Douglas Fir

The great trunks of the Douglas firs almost rival the redwoods in height and diameter. Douglas fir comes in first after fire and stands for about 2,000 years. Here as in the western larch and western white pine forest the western red cedar and hemlock come in as an understory and if the forest is left undisturbed will eventually replace the Douglas fir. Sitka spruce is an important tree in the coast valleys.

This forest covers western Washington and Oregon from the Cascades to the Pacific. It is one of the finest forest types in the world and has given way in Washington and Oregon to agricultural lands, chiefly in hay and pasture, supporting dairying and poultry raising.

Judging from the lands that have been cleared for farm use, the soils under the forest are Gray-Brown Podzolic, such as the Olympic, Melbourne, Everett, Alderwood, and the Willamette-Amity series. In the higher mountains this forest type probably occurs on raw land which is showing a tendency to become podzolic.

Redwood

A great forest of old trees standing close and occupying a relatively narrow strip along the Pacific Ocean from the Oregon line to just above San Francisco Bay, with outstanding groves as far south as Santa Cruz. It is often associated with Douglas fir.

The soils are similar to those under Douglas fir and are Gray-Brown Podzolic.

Ponderosa Pine and Douglas Fir (Western Pine Forests)

This pine forest covers all of the mountains of the West, occupying rather large areas in every State west of the 103d meridian with the exception of Texas and Nevada, where there are relatively small forests of this type.

The forest can be divided as follows:

Lodgepole pine of the Rockies in Colorado, Utah, Wyoming, Montana, and Idaho—also important in parts of Washington, Oregon, and California.

Ponderosa pine and sugar pine, chiefly confined to the Coast Range and west slopes of the Sierras in southern Oregon and California. Incense cedar and white fir are important trees in this forest.

Western larch and Douglas fir, in western Montana and Idaho, occupy a position intermediate between western white pine and ponderosa pine and Douglas fir.

Rocky Mountain Douglas fir, usually located above and on better sites than the ponderosa pine, with which it mixes along a broad contact zone.

Ponderosa pine is the most extensive and most important of the trees of the northwestern pine forests. West of the Sierras it occupies the drier slopes and flats. East of the Sierras, ponderosa and the closely related Jeffrey pine occupy the timbered slopes. Ponderosa pine is important in every Western State and pushes down over the short grass of the Plains across Montana and into the Dakotas and Nebraska, extending over so great an area that it is found at elevations ranging from 2,500 to about 9,000 feet. It lies within the transition zone of the biologists and indicates climatic and soil conditions that are relatively uniform throughout its range.

It is difficult to correlate the western pine forests with soils as described by the Soil Survey Division, since as a rule these soils lie above the agricultural valleys and have not yet received critical study. They are chiefly the arid, subhumid soils such as Underwood-Babb or, under the Pacific forests, the Red and Yellow Podzolic Aiken-Konotki-Sites soils. As a rule ponderosa pine does well on raw land but in great stands the soils are very moist in winter. They may therefore be waterlogged at the surface and become podzolic. At the same time there is a tendency on the drier side to push out on the dark-brown soils of the Pedocals. This is to a great extent indicated by accompanying vegetation. Arizona fescue forms a continuous grass cover in places over the floor of the ponderosa pine forest of the southern Rockies. Blue grama also pushes up into this forest in many places. Idaho fescue in the northern Rockies behaves much as does Arizona fescue in the southern Rockies. It is not surprising, therefore, to find both Pedocals and Pedalfers under the ponderosa pine forests. Accompanying vegetation rather than ponderosa pine should be the indicator.

Juniper-Piñon (Southwestern Coniferous Woodland)

A belt lying below the ponderosa pine forest is in many places occupied by juniper and piñon. It is replaced in southern Arizona and California and to some extent in portions of Utah and Colorado by a chaparral. The junipers are chiefly Rocky Mountain red cedar, Utah, one-seeded, and alligator junipers, and there are two piñons. Juniper has a tendency to predominate at lower levels. In the Great Basin and in the north, juniper gives way at lower elevations to sagebrush, while farther south it may be replaced by desert grassland. Often the trees are scattered and the woodland is very open. The soils are drier than those under ponderosa pine forests. In Oregon the soil under the juniper woodland is classified as arid, subhumid McCammon-Deschutes. In many places in the woodland the erosion loss is so great that there can be no developed soil.

Chaparral

This is a mixed association of small trees or shrubs. In Utah, Colorado, New Mexico, and Arizona it may consist for the most part of deciduous oaks. It is most typical of southern Arizona and southwestern California and varies from a dense low stand of evergreen shrubs to a scattered oak savanna. Probably much of the shrub area is the result of fire.

Much of the more favorably located land has been developed for subtropical agriculture with the help of irrigation. In southern California and in Arizona the soils are noncalcic Browns such as the Vista-Holland-Sierra types. Much of the soil material under this association is young and undeveloped.

APPENDIX

Plant Communities as Indicators of Growth Conditions

Temperature Conditions

Cool climates:
- Northern coniferous forests.
- Northwestern coniferous forests.
- Western pine forests.
- Northeastern pine forests.
- Northeastern hardwoods.
- Northern desert shrub.
- Alpine meadow.

Warm climates:
- Southwestern coniferous woodland.
- Southwestern broad-leaved woodland.
- Southern desert shrub.
- Desert grassland.
- Desert savanna.
- Southeastern hardwoods.
- River-bottom forests.
- Southeastern pine forests.
- Subtropical forests.

Moisture Conditions

High rainfall:
- Northern coniferous forests.
- Northwestern coniferous forests.
- River-bottom forests.
- Southeastern pine forests.
- Southeastern hardwoods.
- Northeastern hardwoods.
- Northeastern pine forests.
- Prairie grassland.

Low rainfall:
- Southern desert shrub.
- Northern desert shrub.
- Desert grassland.
- Plains grassland.
- Desert grass savanna.
- Southwestern coniferous woodland.
- Southwestern broad-leaved woodland.

Drought

Drought enduring:
- Desert grassland.
- Desert grass savanna.
- Plains grassland.
- Southern desert shrub.
- Northern desert shrub.

Nondrought enduring:
- Northern hardwoods.
- Southern hardwoods.
- River-bottom forests.
- Northeastern pine forests.
- Southeastern pine forests.
- Northern coniferous forests.

Soil-Moisture Conditions

Permanently dry subsoil:
- Plains grassland.
- Desert grassland.
- Desert grass savanna.
- Northern desert shrub.
- Southern desert shrub.
- Pacific grassland.
- Southwestern coniferous woodland.
- Southwestern broad-leaved woodland.

Permanently moist subsoil:
- Northern coniferous forests.
- Northeastern pine forests.

Permanently moist subsoil—Contd.
- Northeastern hardwoods.
- Southeastern hardwoods.
- Prairie grassland (greater portion).
- Northwestern coniferous forests.
- Western pine forests (greater portion).
- Alpine meadow.

Flooded condition:
- Parts of northern coniferous forests.
- Marsh grassland.
- River-bottom forests.
- Mangrove.

Valuable for Agricultural Production

Prairie grassland.
River-bottom forests.
Southern hardwoods.
Southeastern pine forests.
Northeastern hardwoods.
Northwestern coniferous forests (parts only).
Pacific grassland (parts only).
Desert grass savanna (parts only).
Plains grassland (parts only).

Valuable Grazing Land

Prairie grassland.
Plains grassland.
Pacific grassland.
Alpine meadow.
Western pine forests.
Desert grass savanna.
Desert grassland.
Northern desert shrub.
Southern desert shrub.

Vegetation Types Found on Western Raw Lands

These types are listed as indicators of the value of the land for the production of small grains, for forage crops, and for grazing (7).

On a long-time basis it is doubtful if any use can equal the forage value of the natural vegetation.

For the Production of Small Grains

Best types:

- Blue grama and valley sage.
- Blue grama, junegrass, and needle-and-thread.
- Needle-and-thread.
- Blue grama and pasture sagebrush.
- Blue grama and sagebrush.
- Blue grama and wild alfalfa.
- Mountain brushland.
- Sheep fescue.

Medium types:

- Arizona fescue.
- Bluebunch wheatgrass.
- Blue grama, buffalo grass, and wild alfalfa.
- Dry meadow.
- Bitterbrush.
- Red three-awn.
- Blue grama and buffalo grass.

Medium types—Continued.

- Blue grama, buffalo grass, and bluestem.
- Blue grama, "niggerwool," and junegrass.
- Weed grass.
- Blue grama, buffalo grass, and red three-awn.
- Blue grama, buffalo grass, and needle-and-thread.
- Blue grama and bluestem.
- Oak chaparral.

Poorest types:

- Sagebrush.
- Bluestem.
- Blue grama and niggerwool.
- Little rabbitbrush.
- Blue grama.
- Giant wild-rye.

For the Production of Forage

Best types:

- Little bluejoint.
- Aspen.
- Mountain weed.
- Mixed mountain grassland.
- Blue grama, buffalo grass, and broom snakeweed.
- Blue grama, buffalo grass, and soapweed.
- Willows.
- Hairy grama, blue grama, and sand sage.
- Blue grama, buffalo grass, and mesquite.
- Mesquite and mesquite grass.
- Blue grama and broom snakeweed.

Medium types:

- Sand hills mixed.
- Black grama.
- Blue grama and fourwing saltbush.
- Rothrock grama.
- Southwestern mountain brush.
- Conifer timber.
- Woodland timber.

Poorest types:

- Shinnery oak.
- Black grama and tobosa.
- Tobosa.
- Black grama and three-awn.
- Black grama, "niggerwool," and sagebrush.
- Niggerwool.
- Yucca desert grassland.
- Wedgeleaf ceanothus.

Grazing Lands[3]

	Carrying capacity[4]
Best types:	
Wet meadows	100–300
Salt grass	50–150
Sacaton	50–100
Alkali sacaton	50–100
Galleta	25–100
Rabbitbrush and alkali sacaton	20–40
Mountain-mahogany	15–40
Greasewood and saltgrass	10–40
Winterfat—sheep	50–100
Medium types:	
Mesquite and fourwing saltbush	10–30
Creosotebush—desert grass	10–20
Blackbrush—desert grass	10–20
California mixed brush	10–20
Desert brush type	5–12
Big galleta	5–10
Mesquite	5–10
Shadscale—sheep	25–100
Salt sage—do	25–75
Greasewood—shadscale—do	25–75
Greasewood—salt sage—do	25–75
Medium types—Continued.	
Greasewood—sheep	25–50
Big saltbush	
Hop-sage—sheep-winter	
Poorest types:	
Small sagebrush	5–10
Scab sagebrush	5–10
Desert sage	5–10
Creosotebush	0–10
Creosotebush—cacti	0–10
Creosotebush and bur-sage	0–10
Blackbrush	0–10
Nolina	
Fourwing saltbush	
Creosotebush—ocotillo	
Shrub buckwheat	
Encelia and California sagebrush	
White sage	
Pickleweed	
Seepweed	
Samphire	
Arrowweed	
Giant cactus and bur-sage	
Coleogyne	

Common and Scientific Names of Plants Mentioned

Alkali sacaton (tussock grass)	*Sporobolus airoides* Torr.
Alligator juniper	*Juniperus pachyphloea* Torr.
Alpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Arizona fescue	*Festuca arizonica* Vasey
Arrowweed	*Pluchea sericea* (Nutt.) Cov.
Ash	*Fraxinus* spp.
Asters	*Aster* spp.
Balsam fir	*Abies balsamea* (L.) Mill.
Balsamroot	*Balsamorhiza sagittata* (Pursh) Nutt.
Beech	*Fagus grandifolia* Ehrh.
Big bluejoint	*Andropogon furcatus* Muhl.
Big galleta	*Hilaria rigida* (Thurb.) Benth.
Big saltbush	*Atriplex lentiformis* (Torr.) S. Wats.
Bitterbrush	*Purshia tridentata* (Pursh) DC.
Bitternut hickory	*Hicoria cordiformis* (Wang.) Britt.
Blackbush	*Coleogyne ramosissima* Torr.
Black grama	*Bouteloua eriopoda* Torr.
Blackjack oak	*Quercus marilandica* Muench.
Black spruce	*Picea mariana* (Mill.) B. S. P.
Blueberry	*Vaccinium* spp.
Bluebunch wheatgrass	*Agropyron spicatum* (Pursh) Scribn. and Sm.
Blue grama	*Bouteloua gracilis* (H. B. K.) Lag.
Bluejoint	*Andropogon* sp.
Bluestem (western wheatgrass)	*Agropyron smithii* Rydb.
Boxelder	*Acer negundo* L.
Bromes	*Bromus* spp.
Broomsedge	*Andropogon glomeratus* (Walt.) B. S. P.
Broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britt. and Rusby
Buffalo grass	*Buchloë dactyloides* (Nutt.) Engelm.
Bur-sage	*Franseria* spp.

[3] Types probably more valuable as well-managed grazing lands than for any type of crop production.
[4] Estimated number of cattle per square mile for an average year.

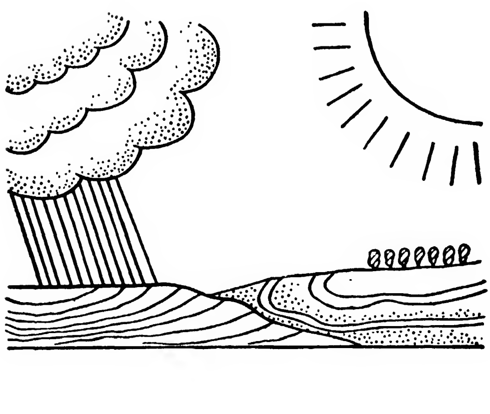
California needlegrass	*Stipa pulchra* Hitchc.
California red fir	*Abies magnifica* Murr.
California sagebrush	*Artemisia californica* Less.
Cane cactus	*Opuntia* sp.
Chamiso	*Atriplex canescens* (Pursh) Nutt.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Chestnut oak	*Quercus montana* Willd.
Coleogyne (blackbush)	*Coleogyne ramosissima* Torr.
Coneflower	*Ratibida columnaris* (Sims) D. Don
Corkbark fir	*Abies arizonica* Merriam
Cottonwood	*Populus balsamifera* L.
Creosotebush	*Covillea tridentata* (DC.) Vail
Cryptanthe	*Cryptanthe crassisepala* (T. & G.) Greene
Curly-mesquite	*Hilaria belangeri* (Steud.) Nash
Cypress	*Taxodium distichum* (L.) Rich.
Desert saltbush	*Atriplex polycarpa* S. Wats.
Dogwood	*Cornus* spp.
Douglas fir	*Pseudotsuga mucronata* (Raf.) Sudw.
Downy chess	*Bromus tectorum* L.
Elm	*Ulmus americana* L.
Encelia	*Encelia* sp.
Engelmann spruce	*Picea engelmanni* (Parry) Englem.
Filaree	*Erodium* spp.
Fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.
Galleta	*Hilaria jamesii* (Torr.) Benth.
Giant cactus	*Carnegiea gigantea* (Engelm.) Britt. and Rose
Giant wild-rye	*Elymus condensatus* Presl
Goldenrods	*Solidago* spp.
Greasewood	*Sarcobatus vermiculatus* (Hook.) Torr.
Hairy grama	*Bouteloua hirsuta* Lag.
Hemlock	*Tsuga canadensis* (L.) Carr.
Hickory	*Hicoria* spp.
Hop-sage	*Grayia spinosa* (Hook.) Moq.
Idaho fescue	*Festuca idahoensis* Elmer
Incense cedar	*Libocedrus decurrens* Torr.
Indian grass	*Sorghastrum nutans* (L.) Nash
Jack pine	*Pinus banksiana* Lamb.
Jeffrey pine	*Pinus jeffreyi* A. Murr.
Junegrass	*Koeleria cristata* (L.) Pers.
Lambsquarter	*Chenopodium album* L.
Lilies	*Lilium* sp.
Little bluejoint	*Andropogon scoparius* Michx.
Little rabbitbrush	*Chrysothamnus stenophyllus* (A. Gray) Greene
Loblolly pine	*Pinus taeda* L.
Lodgepole pine	*Pinus contorta* Dougl.
Longleaf pine	*Pinus palustris* Mill.
Lyall larch	*Larix lyallii* Parl.
Mesquites	*Prosopis* spp.
Mockernut hickory	*Hicoria alba* (L.) Britt.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Mountain-mahogany	*Cercocarpus* spp.
Narrowleaf saltbush	*Atriplex linearis* S. Wats.
Needle-and-thread	*Stipa comata* Trin.
Niggerwool	*Carex filifolia* Nutt.
Noble fir	*Abies nobilis* Lindl.

Oaks	*Quercus* spp.
Ocotillo	*Fouquieria splendens* Engelm.
One-seeded juniper	*Juniperus monosperma* (Engelm.) Sarg.
Paloverde	*Cercidium* sp.
Paspalums	*Paspalum* spp.
Pasture sagebrush	*Artemisia frigida* Willd.
Peppergrass	*Lepidium ramosissimum* A. Nels.
Pickleweed	*Allenrolfea occidentalis* (S. Wats.) Kuntze
Pignut hickory	*Hicoria glabra* (Mill.) Britt.
Pine bluegrass	*Poa scabrella* (Thurb.) Benth.
Piñon	*Pinus edulis* Engelm. and *Pinus monophylla* Torr. and Frem.
Porcupine grass	*Stipa spartea* Trin.
Ponderosa pine	*Pinus ponderosa* Dougl.
Psoralea	*Psoralea* spp.
Purple coneflower	*Echinacea* sp.
Red bay	*Persea borbonia* (L.) Spreng.
Red gum	*Liquidambar styraciflua* L.
Red maple	*Acer rubrum* L.
Red oak	*Quercus borealis maxima* (Marsh.) Ashe
Red pine	*Pinus resinosa* Ait.
Red samphire	*Salicornia rubra* A. Nels.
Red spruce	*Picea rubens* Sarg.
Red three-awn (wire grass)	*Aristida longiseta* Steud.
Redwood	*Sequoia sempervirens* (Lamb.) Endl.
Ring muhly	*Muhlenbergia torreyi* (Kunth) Hitchc.
Rothrock grama	*Bouteloua rothrockii* Vasey
Rocky Mountain red cedar	*Juniperus scopulorum* Sarg.
Russian-thistle	*Salsola pestifer* A. Nels.
Sacaton	*Sporobolus wrightii* Munro
Sagebrush	*Artemisia tridentata* Nutt.
Saltbush	*Atriplex nuttallii* S. Wats. or *Atriplex corrugata* S. Wats.
Saltgrass	*Distichlis stricta* (Torr.) Rydb.
Salt sage	See Fourwing saltbush.
Samphire	*Salicornia* sp.
Sandberg bluegrass	*Poa secunda* Presl
Sandgrass	*Calamovilfa longifolia* (Hook.) Scribn.
Sand sage	*Artemisia filifolia* Torr.
Scabland sage	*Artemisia rigida* A. Gray
Scab sagebrush	*Artemisia* sp.
Scrub pine	*Pinus virginiana* Mill.
Selaginella	*Selaginella* sp.
Seepweed	*Dondia torreyana* (S. Wats.) Standley
Shadscale	*Atriplex confertifolia* (Torr.) S. Wats.
Sheep fescue	*Festuca ovina* L.
Shinnery oak	*Quercus* spp.
Shortleaf pine	*Pinus echinata* Mill.
Shrub buckwheat	*Eriogonum* sp.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Sixweeks fescue	*Festuca octoflora* Walt.
Slash pine	*Pinus caribaea* Morelet
Slender wheatgrass	*Agropyron pauciflorum* (Schwein.) Hitchc.
Small sage	*Artemisia nova* A. Nels.
Snakeweed	*Gutierrezia sarothrae* (Pursh) Britt. and Rusby
Soapweed	*Yucca elata* Engelm.
Sprucetop grama	*Bouteloua chondrosioides* (H. B. K.) Benth.
Sugar maple	*Acer saccharum* Marsh.
Sugar pine	*Pinus lambertiana* Dougl.
Sweet bay	*Magnolia virginiana* L.
Switchgrass	*Panicum virgatum* L.

Tamarack	*Larix laricina* (DuRoi) Koch
Tarweeds	*Hemizonia* spp.
Three-awn grasses	*Aristida* spp.
Tobosa	*Hilaria mutica* (Buckl.) Benth.
Tupelo gum	*Nyssa aquatica* L.
Utah juniper	*Juniperus utahensis* (Engelm.) Lemmon
Utah samphire	*Salicornia utahensis* Tidestrom
Valley sage	*Artemisia cana* Pursh
Walnut	*Juglans nigra* L.
Water ash	*Fraxinus caroliniana* Mill.
Water grass	*Paspalum dilatatum* Poir.
Wedgeleaf ceanothus	*Ceanothus cuneatus* (Hook.) Nutt.
Western larch	*Larix occidentalis* Nutt.
Western stickseed	*Lappula occidentalis* (S. Wats.) Greene
Western red cedar	*Thuja plicata* D. Don
Western white pine	*Pinus monticola* Dougl.
White cedar (southern)	*Chamaecyparis thyoides* (L.) B. S. P.
White fir	*Abies concolor* (Gord.) Parry
White pine	*Pinus strobus* L.
White sage	*Kochia vestita* (S. Wats.) Rydb.
Wild oats	*Avena fatua* L.
Willows	*Salix* spp.
Winterfat	*Eurotia lanata* (Pursh) Moq.
Woolly Indianwheat	*Plantago purshii* Roem. and Schult.
Yellow birch	*Betula lutea* Michx. f.
Yellow poplar	*Liriodendron tulipifera* L.
Yellow oak (black oak)	*Quercus velutina* Lam.
Yucca	*Yucca* spp.

Part IV Soils & Men

Fundamentals of Soil Science



BACK of soil use and land planning for the best interests of the community, back of soil management by the individual farmer, lies a growing body of scientific knowledge regarding the true nature of the soil. The scientist working in this field would be the first to say that his knowledge is far from perfect—that there is more to be discovered than is yet known. But the practical handling of the soil must rest solidly on what scientific knowledge we do have. It is when men abuse the soil, disregarding its true nature, that they make the most disastrous mistakes, for which nature exacts penalties.

Physics, chemistry, and biology all contribute to our knowledge of the soil. In this part of the Yearbook, an effort is made to summarize the main outlines of this science as it is understood today. The first article gives a soil scientist's philosophy of the part played by soil in the affairs of mankind. Following this are articles on the physical nature, the water relations, and the chemistry of the soil. The role of organic matter and the activities of living organisms in the soil are then discussed. Next, all of these factors and others are brought together and the results of the interplay of forces in forming soil are described. Following this is an article on the rather complex business of classifying soils according to the principles worked out in recent years. The concluding article tells how soil maps are made and what information they contain.

SOCIETY has its roots in the soil. Do the different broad types of soil on which men live result in different types of civilization? What happens when people migrate from one type of soil to another with which they are unfamiliar? Do civilizations fall because the soil fails to produce—or does a soil fail only when the people living on it no longer know how to manage their civilization? This article discusses such fundamental questions, and concludes with a brief account of the development of soil science as we know it today.

Soil and Society

By Charles E. Kellogg [1]

AN AGRICULTURE secure from domestic or foreign exploitation and protected from invaders always holds a key place in stable societies. Such societies have roots in their homelands, developed by long living on the same soil, each generation building upon the traditions of the previous one. In a complete culture or civilization, agriculture, trade, science, and the arts all develop together; but the stability of existence and continuity of effort required for this development depend, most of all, on sustained productivity of the soil, which in turn requires management by a secure and virile population of home-makers on the land. The great cultural systems that have made their mark in world history have been built upon agriculture, though their subsequent expansion in industry or trade may have seemed to overshadow these rural beginnings.

Early man was a ranging nomad, constantly changing his abode from landscape to landscape,[2] always in search of new hunting grounds or fresh pastures. Great nomadic kingdoms grew up on the grasslands of central Asia, but they had no stability, no roots, and left few marks on the pages of world history and certainly less on those of civilization; they accomplished little of importance until they settled down—ceased to be nomadic.

The birth of primitive agriculture was the birth of civilization, and with it there came a great change. Occupational classes developed more sharply and definitely, and among many of the people the plow

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[2]The word "landscape" as used in soil geography means the sum total of the characteristics that distinguish a certain area on the earth's surface from other areas. These characteristics are the result not only of natural forces but of human occupancy and use of the land. Included among them are such features as soil types, vegetation, rock formations, hills, valleys, streams, cultivated fields, roads, buildings. All of these features together give the area its distinguishing pattern, which is the landscape.

replaced the sword. These men worked with nature, not to steal but to sow. As a farmer, man himself became closely attached to the landscape, firmly rooted to the soil that supported him At times the soil seemed bountiful and kindly and again stubborn and unfriendly, but it was always a challenge to man's cunning. He learned to adapt his ways accordingly.

SOIL AND LANDSCAPE

Soil is the natural medium for the growth of plants. Although most soil is produced from weathered rocks, the rain and the sun have changed them greatly. Of still more importance are those changes made by the plants themselves. Thus soil is made through the influence of both physical and biological forces. It is especially the biological forces that give those characteristics to a soil or landscape that are most important to man. Essentially, all life depends upon the soil, and its important functional attribute, productivity for plants, is due more than to anything else to the operation of biological forces, particularly vegetation. There can be no life without soil and no soil without life: they have evolved together.

All features of the natural landscape, conceived as the total environment for living organisms, are interdependent. There is a relationship between climate and vegetation, between parent rock and vegetation, between age and slope, and even between climate and slope All express themselves in the soil, which is the final synthetic expression of the forces in the natural landscape working together, and by which the nature of the landscape can be characterized better, more completely, and more directly than by any other factor or combination of factors.

Since there is a vast number of possible combinations of these climatic, geological, and biological forces in the world, there is a great number of types of soil; yet these can be grouped conveniently into a smaller number of great soil groups, each having particular characteristics of fundamental significance to the development of human society. Each is characterized by certain internal physical and chemical properties and by certain external features of climate and vegetation (fig. 1).

Every soil type, local or general, has its own elastic limit; each offers certain possibilities, and each has rather definite limitations of production within the particular economic and social framework existing at any time. In any one great soil group there are particular types of food available to man; the landscape exerts certain aesthetic or psychological influences; and within each group particular types of agricultural techniques and social organizations are necessary for man to establish himself.

Soil and Food

Man obtains from the soil, first of all, his food. Primitive man must adapt himself physically to the diet that nature furnishes or move to a more agreeable place. Since the composition of the diet has a pronounced influence upon the physical formation of both men and animals, and since the foods that compose it depend, in turn, upon the soil that produces them, it is not surprising that there are physical variations in people from place to place. As soon as people move

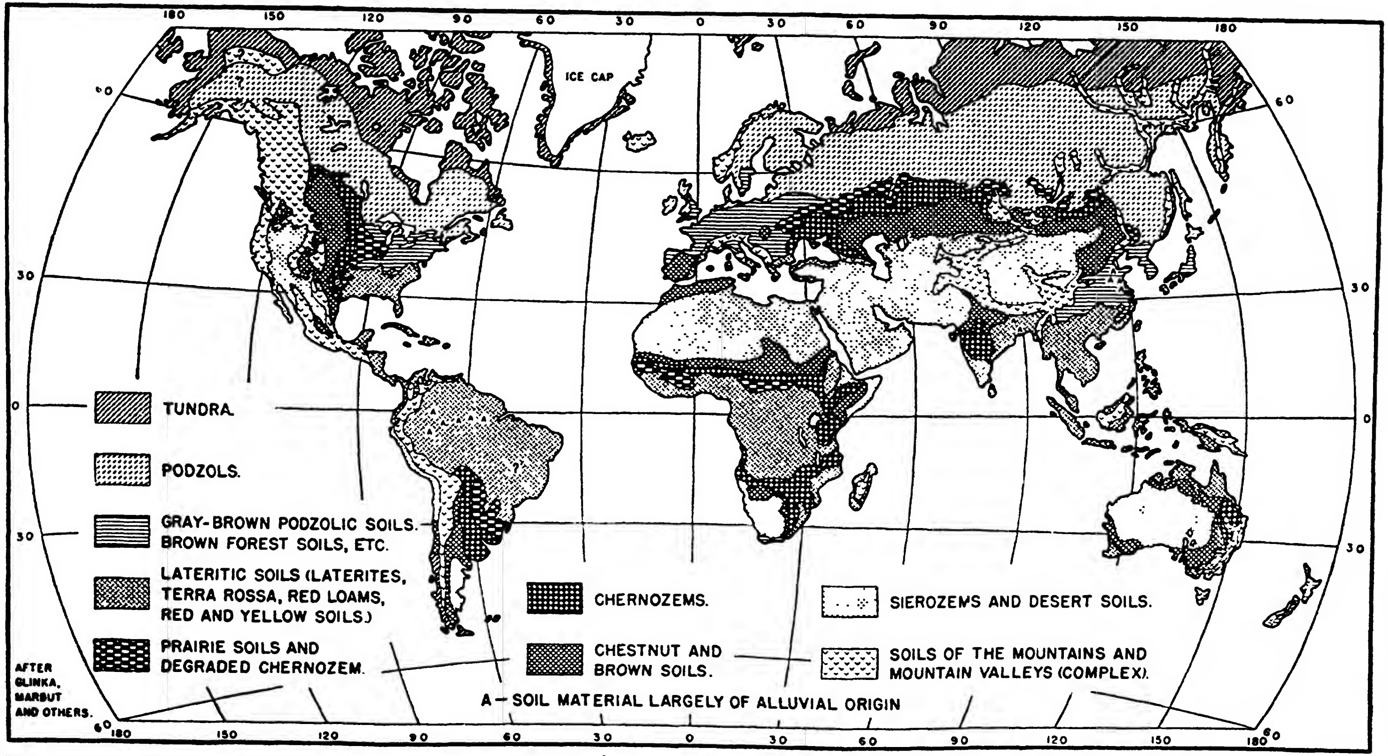

FIGURE 1.—Schematic map of primary groups of soils in the world (see pp. 996 to 1001 for descriptions). Some interesting similarities and contrasts between the people and social institutions in various parts of the world may be partially explained from this map.

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from one soil to another, a new adjustment is forced by the conflict between the genetic inheritance and the new environment.

With the advancement of knowledge and improvements of technique man is able to improve the products of the soil, according to his requirements and taste, through careful breeding and fertilization. Although several deficiencies, such as those of calcium, phosphorus, and nitrogen, may be corrected by the modern scientist, many of the minerals and vitamins necessary to man occur in such small quantities in plants that their presence and effects still remain obscure. Each of the great soil groups is characterized by certain general levels of plant nutrients. The forested soils of western Europe and eastern United States, for example, are commonly low in phosphorus, calcium, and the bases generally. In the great grassland areas of central North America and Eurasia these nutrients may be plentiful, but iodine may be deficient. Many soils in the humid Tropics are especially deficient in phosphorus. Local soil types may have excesses or deficiencies of such elements as sodium, magnesium, selenium, chlorine, cobalt, nickel, iron, boron, or copper responsible for significant influences upon food plants.

The different races of men, which may be regarded as the finished products in the evolution of a landscape, seem to have developed in restricted localities, each having particular soil conditions as far as the minerals available for plant growth are concerned. Those individuals who survived, over a period of many generations, were those able to adjust themselves to an iodine shortage, a phosphorus shortage, a calcium shortage, an excess of common salt, or whatever local situation obtained. These adjustments called for others, and a distinct physique developed.

With increased trade, the diet of the ordinary person is obtained from a wide group of soils and is less likely to be seriously deficient in some one respect. During previous periods of history, however, food came from a very restricted region, and even today, among backward peoples and in certain low-income groups, a similar situation exists. Under such conditions especially, the diet may have a pronounced effect upon health and disease. Susceptibility to disease, for example, may be induced through poor nutrition long before a direct effect is noted in the outward appearance. It is thought that gland failures frequently are due to an attempt to make an adjustment to a mineral deficiency and also that such deficiencies may have a pronounced influence upon the general physical development of the whole race (*242*).[3]

Aesthetic Influences of Place

Man receives inspiration as well as physical necessities from the soil he occupies. The folk songs of the world are less expressive of the people than of the landscape in which they originated. It is the songs of the mountains, of the desert, of the plains, of the forest, and of the jungles that are distinctive. The powerful influence of the landscape is reflected in literature.

One scarcely realizes these differences until he travels from his own region to another, or until he studies the art of an alien race. People

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

from western Europe and eastern United States have emphasized the grandeur of the desert, the mystery of the steppe, and the horror of the jungle, not realizing that their own landscape is emotionally oppressive to the stranger.

AGRICULTURAL TECHNIQUES

The needs of man extend far beyond what nature, unassisted, can furnish him. He must plow and sow—he must work with nature and conduct her producing forces through carefully organized channels. From the accumulation of experience and knowledge, man gradually learns to bend natural forces to his advantage and thus reduce the hazards of life and lessen his direct dependence upon the natural environment. Thus it is through the use of techniques that civilized man produces his particular necessities.

Yet no matter how complicated become these techniques, social or individual, the fundamental fact of agriculture, the relationship between the plant and the soil in which it grows, remains. The very responsiveness of soil to technique is one of its unique characteristics, individual and finite. Unconsciously man adjusts himself to these physical requirements, individually and collectively. His daily life, his work and his play, from the simple acts of life to the more complicated economic mechanisms he creates, are conditioned by the necessities of his landscape. The agricultural techniques that man employs are basically designed to produce a relationship of soil to plant suitable to the aims of man.

Theoretically, there are two general approaches to this adjustment: (1) Change the soil; or (2) choose plants to fit the soil. Usually man combines the two to some extent. While the proper selection of plants most nearly adapted to the natural soil is of the utmost importance, only rarely can crops be grown without tillage and other assistance from man. Further, the plants naturally adapted to the various soils vary greatly in their usefulness to mankind. Through the use of techniques many soils can be made productive of other than the native plants.

These agricultural techniques may be divided roughly into two classes: (1) Those more or less simple methods carried out by the farmer and his family with relatively simple implements. For centuries these have been developing according to the conditions under which the farmers found themselves. (2) Those techniques more directly dependent upon the collective effort of the social group as a whole—the social techniques. Included in this group are those which may be largely physical, such as the development of electric power, and others that are largely institutional or legal. These are determined by the state of knowledge, basic interests, and cultural outlook of the group.

The Simple Techniques

Many of the simple techniques are very old indeed, and their origins are lost in antiquity. One may read in Homer how Odysseus, upon returning from his wanderings, was recognized by his dog lying on a heap of refuse "with which the thralls were wont to manure the land." The development of the hoe, the ax, and even of the plow (except the

tractor plow) has been slow and gradual, almost historyless. In the Old Testament (I Samuel xiii: 20) we find that the Israelites "went down to the Philistines to sharpen every man his share, and his coulter, and his axe, and his mattock." How different, really, were these simple practices of 3,000 years ago from ours today?

Plowing is the oldest and most fundamental technique, and in one way or another it is practiced by farmers everywhere.

> Homer and Hesiod and Virgil knew
> The ploughshare in its reasonable shape,
> Classical from the moment it was new,
> Sprung ready-armed, ordained without escape,
> And never bettered though man's cunning grew,
> And barbarous countries joined the classic reach.
> Coulter and singletree and share and haft
> Frugal of ornament as peasant's speech,
> Strong to their use and simple as their craft,
> Whether to turn the ridge or cleave the rean.
> (V. Sackville-West, The Land.)

One may find the simple practices suited to the soils of Italy explained in Columella's Husbandary (about A. D. 50) with amazing acumen, even when viewed in the light of modern knowledge. Although Columella remained the authority on agriculture for more than 14 centuries, he made no claim to originality, in the sense of invention.

> But whatever those things be, which, because of the rural discipline of our times, are not agreeable to the opinion or practice of the antients, they ought not to deter the learner from reading. For, with the antients, there are many more things which deserve to be commended and approved by us, than to be rejected (*73*).

Although he draws upon the work of Mago the Carthaginian and many others, he warns that regions having different soils, "being of a different nature, cannot produce the same increase, or yield the same plenty."

Of course, changes and improvements have been made in the simple techniques, especially in the exactness with which the practices are used on particular types of soil, but on the whole the basic techniques employed on the self-sustaining, noncommercial farms have developed very slowly, in marked contrast to the social techniques.

The Social Techniques

The social group must adapt its methods to the soil just as the farmer must use practices fitted to his own particular land. Unless such an adjustment is attained, part or even all of the individuals within the group may find themselves quite helpless to adjust their separate enterprises to their own land. As an example, one might think of those farmers on the sloping red lands of the South, growing corn and cotton on soils that erode easily. Perhaps the individual has failed in the application of his own techniques; certainly some farmers have done better than others in the same community and on the same soils. But until the social group makes certain adjustments, some individuals may be unable to adopt those practices which will conserve the land and maintain their homes. The control of soil erosion in this region and many others is not unrelated to tenancy, agricultural credit, and other problems requiring collective effort for solution.

Devices for long-distance marketing, including railroads and other means of communication, irrigation, manufacture of power machinery, manufacture and distribution of chemical fertilizers, the development of electric power, the processing and storage of farm products, and legal devices regarding the tenure, use, and disposal of land are obvious examples of social techniques that have a direct bearing upon the relationship between the farmer and his soil.

Man acting as an individual cannot easily supply water to desert soils. He may not be able to provide the soil with the necessary fertilizer. He cannot arrange for protection by military or legal means. He cannot build railroads. Organized society can do these things. Provisions for long-term land tenure must be made by the social group and will depend upon the nature of the soil and the social outlook of the group. If the legal or economic arrangements adopted are not in accordance with the physical requirements of the land, either the people or the land, or, as is more likely, both, will deteriorate.

The development of new social techniques may change the relationship of other techniques to the soil. The construction of railroads, for example, may have the effect of allowing wheat farming in small units in place of ranching in large units; but of course, not unless the soil is physically adapted to wheat growing. The use of any soil cannot be changed beyond a certain elastic limit.

Of particular importance right now is the increase in farm and community refrigeration with the development and cheapening of electric power. Refrigeration frequently is a determining factor in the production of certain animal products and the use of land for pasture. The use of electric power, located at the margins of fields, for tillage and harvesting, is hardly beyond the suggestion stage, but it may prove a great advantage on soils injured by heavy machinery. If present trends continue, electric power will certainly have a profound effect upon agriculture and the use of soils during the next few decades.

Changes in land tenure, together with fertilization and other techniques, have made possible sugar production on a large scale on soils previously used by native gardener-farmers. Many other examples will come to the mind of the reader. Theoretically there is almost no limit to production on any land, provided enough is done in the way of fertilization, irrigation, and so on. If necessary, a glass house may be built over it for temperature control.

In the real world, however, there is an ill-defined, never-stable, maximum elastic limit for each soil beyond which production cannot be increased without a serious decline in labor income. More often, however, the exploitation of land and the people on it comes about from an unconscious lack of adjustment between the soil and the social techniques than from any conscious attempt to increase production. If those farmers growing cotton on the rolling red lands of the South found themselves in a social group where long tenure of the land was possible, with devices for long-term agricultural credit and for furnishing them cheap fertilizer and cheap electric power, they might have a greater opportunity to use their lands for close-growing, erosion-reducing crops—legumes and grasses. Thus they might save both themselves and the land.

RACE AND SOIL

Men and societies are thus products of the landscape. The strong race has first approached a physical and social equilibrium with its own landscape. The great cultural systems, whose subsequent civilizations have made their mark on world history, have, for the most part, originated in a particular landscape on a particular group of soils—the Egyptian, on the alluvial soils of the desert in the Nile Valley; the Arabian, in the semidesert; the classical (Greece and Rome), on the Red soils; and the western, on the leached forested soils of northern Europe.

People may move from one landscape to another, but a race is rooted to the soil that gave it birth (*377*). As soon as people move, serious conflicts develop socially and within the individual. Fundamentally the conflict is between the genetic heritage, carried from another soil, and the new landscape with its different possibilities and requirements. Such conflicts reach from the simple life of the individual to the highest grounds of government and politics. In primitive societies these relationships are quite obvious; among highly cultured societies they are complex and obscure but no less important. The development of science offers a way to extend the elastic limit of soils and lessen the direct dependence of society upon the natural soil. Frequently, however, legal and economic devices have lagged so far behind the scientific devices that the latter have been of little use to increase the social welfare of the people—measured by health and education as well as material well-being.

CHANGES IN SOCIETY

A problem of maladjustment between people and their soil may arise in several ways. First, there are the problems that are due to changes in the people on the land, either from internal or from external causes. One technique may develop much faster than others and throw the society out of balance. For example, the importation of modern medical science and sanitary engineering into some countries, as in many tropical colonies, has been responsible for a tremendous increase in population without a corresponding increase in agricultural production and proper development of social institutions. Exploitation of both land and people may be the result. Contrariwise, a declining birth rate may produce a society with a large percentage of adult workers in proportion to the total number of consumers.

A general change in living standards causes changes in the use of soils. These usually come gradually, however, as a rise in living standards is commonly coincident with a development of techniques for the increase of agricultural production. The development of differences in living standards and the formation of classes may have a profound effect upon the adjustment between farmers and their land. Especially before the inventions of modern times, made possible by the rise of science, one group could have an abundance of leisure and a high living standard only at the expense of other groups. Slavery was likely necessary for the golden age of Pericles. Present-day differences probably are less acute, but much greater than appears necessary from the point of view of the physical capabilities for pro-

duction. The Punic Wars cost Rome over 300,000 soldiers, mostly freeholders, farmers near Rome. Slaves were brought in to fill their places, and a landed aristocracy, much deplored by Columella, arose. Not only that, but free bread made available to the Roman citizens depended upon slave-operated farms at the fringes of the Empire.

It is not necessary to stress the great importance of land tenure to the people of the world. The great systems of aristocracy, until recently dominant in Europe, depended upon land ownership. A great many of the people who came to North America from Europe and founded the American democracy were motivated by the desire to own land and realize the security of a farm home (*78, 409*). Early agriculture in the United States was of a subsistence type, and only a little produce needed to be sold in order to buy the few things not provided by the soil, although standards of living were lower than we wish or need to accept now. In the Southern States, however, slaves made possible a different type of farm organization, and a sort of rural aristocracy developed. In those areas the percentage of tenancy today is very high.

The new democracy was a great boon to those who worked for a living, and especially to the farmer. Land was plentiful, and with courage and industry a home could be made. The job of the State was to provide legal and military protection. As time went on, however, the cities took over some of the manufacturing, and the farmer produced more to sell and purchased more goods and services. He became more of a specialist—in cotton in the South and in cattle and later in grain in the West. Land values rose. Low prices were irritating to the colonial farmer, but they are ruinous to the modern farmer. Money is needed for taxes, for interest, for clothing, and for many things that were of little importance or unknown to the colonial farmer. The modern farmer requires from society something besides legal property rights in the land and military protection.

Few people would suggest a return to the type of subsistence farming practiced in colonial times. Farmers want and need the products of modern invention as much as any other group of people. To obtain them, the farmer must have products for sale. He must have money to pay for his public services and to buy the products of the city. The difficulty comes when the thought of immediate cash return, this year and next, dominates over that of the return for a longer period. Quite generally, the type of soil management that gives the greatest immediate return leads to a deterioration of soil productivity, whereas the type that provides the highest income over the period of a generation leads to the maintenance or improvement of productivity.

The farm home owned by the operator has been and still is an ideal in democratic United States. The soil is more than a source of immediate gain; it represents security for the future. To the extent that this attitude, so fundamentally developed among the small farmers in early colonial times, motivates the farmer and his family, the soil is conserved. Conservation, not for itself but for security and that sustained production necessary to security, is an essential part of any system of permanent agriculture.

The Farm and the City

During the early life of a culture, people are close to the land. The seeds of great cultural ideas are germinated in the nursery of undefiled natural landscapes, but their final fruition, their crystallization into dogmas and styles, takes place in cities. The towns of a young culture develop in response to the needs of self-protection and as an expression of the gregarious instincts; but cities may gradually emancipate themselves from the rural landscape and grow apart from the soil as a self-conscious offspring, a creation of uprooted men who have lost their contact with the soil. They cannot survive, however, financially or biologically, except with the support of a healthy, vigorous rural population.

The art of agriculture is inseparable from the art of homemaking. Homemakers are savers—the true conservationists. The substitution of the business of farming for the art of agriculture signified the first encroachment of city ways into agriculture itself. The land and home of the farmer then become capital. Through the inheritance of this capital by farm-born city dwellers, through payment of interest, and in other ways, cities may sap the vitality of the country.

Even though they may gain political control and formulate social and economic policies of their own choosing for the nation, cities in themselves are not necessarily harmful to agriculture and can be very helpful. Indeed, the farmer needs and must have the goods and services of the city if he is to enjoy more than a primitive social life. It is rather the concentration of wealth and credit facilities in the city, especially as associated with absentee ownership, that may work a real hardship on the farmer. As a matter of fact, such controls of credit and finance may be as harmful to large sections of the city's own population as to the country people, if an undue proportion of the fruits of production are diverted away from the producers.

If the cities thus gain power over the country people and use that power in a way that throws them seriously out of adjustment with their landscape, farmers are forced to exploit their land, and there is a decline in soil productivity associated with an inevitable train of social disorders. People say there is an agricultural problem. Inevitably this is accompanied by serious problems in the city itself. A general decline in soil productivity is the effect, not the cause, of these disorders.

Whether such a sequence will take place in our country, with a further increase in tenancy, a general increase in the wealth diverted away from the land, and a decrease in soil productivity, is a matter for speculation. New York State, in spite of its very large city population, has adopted a forward-looking agricultural program. Certainly such a tendency is cause for hope. Although the productivity of our soils is still high, deterioration has been significant during the last generation.

Even more harm has been done to the spirit of large sections of the rural population. This is the really serious aspect of the matter. People without hope do not support democracy. Dictatorships and autocratic governments are accepted by people who have nothing to lose. Men whose only privilege is to exist at the edge of starvation,

humiliated, and with no security for themselves or their families, are easily persuaded to sacrifice their freedom. To them freedom becomes in effect freedom to starve and to sleep under the bridge.

Nationalism and the Farmer

In the struggle for power certain nations may seek to become self-sufficient. Special techniques may be employed in order to produce food and other commodities on soils not naturally suited to such production for a free market. The soils may be used for new crops or for higher yields of crops already grown. At the same time the use of land for other purposes may be discouraged. Through the use of bounties, tariffs, or other devices, governments can, and frequently do, throw the farmer out of adjustment to his landscape, or at least make a new adjustment necessary. At any moment these devices may improve or injure the condition of the individual farmer, depending upon how they influence his own particular farm unit. But if over a long period the tariff or other devices are used to subsidize inefficient production, a serious day of reckoning is likely to come. It is not the purpose to discuss this matter fully here but only to suggest its importance in any consideration of the relationship of the farmer to his land. Frequently the distress in rural areas is due to the influence of such artificial conditions. Again, other seemingly prosperous areas may owe their prosperity to some special economic situation the continuity of which may be broken easily by the caprices of national or international politics.

Some of the most important of these influences may at first glance seem remote from the people affected. For example, an agricultural country producing basic raw materials for foreign trade might find its outlet curtailed through the operation of bounties and tariffs in other countries. If such a country had additional resources, such as iron, coal, and electric power, it might develop industrially and make an approach toward becoming a self-contained unit, with an increase in domestic commerce offsetting all or a part of its previous foreign commerce. If there were not basic materials for industrial development or if certain key resources were absent, such a recourse might be utterly impossible, and the country might find itself in a serious situation, with great capacities for agricultural production but no markets.

Frequently the farmers' interests may come into sharp disagreement with the nation's interest, or what may appear to the government to be the nation's interest. And it is further obvious that in the struggle for national power, untold misery may be brought about through the operation of special economic forces that destroy the adjustment between the people and their soil, even during times of peace.

MOVEMENT OF THE PEOPLE

Not only may problems of adjustment between people and their own soil arise, but other serious problems may develop when people move to a new landscape. Of course, no two regions are identical in all respects but the degree of adjustment that may be necessary varies fundamentally. When the early colonists came to North America they found many new things. Yet the land was forested and well-watered, and the soils were light-colored and leached, much like those of western

Europe. There is little wonder, therefore, that English customs and English common law were easily adapted to the New World. In the southern colonies physical conditions of soil and climate made possible early specialization in cotton and favored the plantation system, as compared to the more general, family-sized farm adapted to the soils farther north. Thus, important differences in the soils of the northern colonies as compared with those of the southern colonies doubtless accounted, in part at least, for corresponding differences in social and economic arrangements relating to their use—differences that reached a critical stage in the middle of the last century.

When people move from one soil to another they bring their old customs and habits with them. Immediately a conflict arises between the old traditions and the new demands. The period of so-called lawlessness in the American plains was a period of such conflict and adjustment. Soil blowing and poverty, following overgrazing and overexpansion of grain growing in part of our western plains, indicate that an adjustment has not yet been reached.

Even though a new society may hold to its old customs and traditions as tenaciously as possible, unless these are replaced as a new equilibrium is established, the society disappears. The more diversified the origin of the people who occupy new areas, the greater their plasticity and the more readily they are able to adjust themselves, their techniques, and their laws to the new situation. The greatly diversified origin of the peoples of the United States probably accounts for their unusual plasticity and their ability to occupy so many different soils. As the population becomes more fixed, more firmly rooted, certain sectional differences in those techniques and institutions which relate directly to the use and capabilities of the soil may become more noticeable. Fortunately for us, that mutual understanding made possible by a common language and free movement of people can aid greatly in dulling the sharpness of these conflicts. The first and fundamental basis for mutual understanding lies in the appreciation that certain techniques and institutions need to be different where the soils are different. In a nation with many soil regions, strict uniformity is inconsistent with democracy, with conservation, and with public welfare.

The most important movement during recent years has been the occupation of the black soils and brown soils of the plains. Although some areas of such soils, as in Rumania, have been used for a long time, the great bulk has come into use since the Thirty Years' War in Europe and especially during the last hundred years. Until the development of railroads and other products of modern invention the great areas of black soils in the world were used chiefly by the nomads and other relatively primitive societies. Since that time the great steppes in Asia and the plains of the Americas and of Australia have become very important as homes for people and for the production of bread grains.

Whereas the soil in the humid regions of, say, western Europe or eastern North America lends itself to the establishment of highly diversified farms with a large measure of self-containment, the soils of the great black lands are especially adapted to grain farming with extensive methods, particularly in the drier portions. The more hazardous climate makes production less certain, more seasonal.

Since these farmers must buy many of the things produced by the farmers of the humid region and therefore are more dependent on a cash income, they are more concerned with and influenced by general economic conditions; and they are impelled more strongly toward cooperation for the protection of their economic interests. Whereas diversification of the farm enterprise offers some escape from the sharper fluctuations of a price economy in humid areas, these possibilities are limited in the plains. The traditions of individualism, developed among the people of the forested soils of western Europe, came into sharp conflict with the demands of the grassland soils. The tendency appears to be toward the development of strong sentiment for cooperation. What the final outcome will be is uncertain.

A considerable change in the type of use to which soils are put may be made by the new occupants of a region, especially when assisted by a military force raised in the homeland. Perhaps some of the most striking examples are to be found on the soils of the Tropics. The native tropical farmer is more a gardener than a farmer. His tools are the spade, the ax, and the hoe, and he requires the minimum of trade with other people. Several of the strong nations built on the soils of the temperate forested regions have colonized these areas and developed a highly efficient, highly capitalized plantation system of agriculture with extreme specialization in sugarcane, bananas, rubber, or other crops. Whether or not the native people are better off, happier, under such a system may be open to question. Even with the same techniques of production, there may be great differences to the people between systems owned locally, in which the wealth produced remains in the area, and those whose ownership is outside. What system will prove to be permanent and adapted to the soil is a question that will arise when outside support is withdrawn.

These examples serve to emphasize the importance to the land and the people of the influence of people outside the land itself. Although each soil type may be said to have an elastic limit beyond which its use cannot be pushed, the particular point at which this limit is found at any time depends upon economic conditions. Men work and live in a social world, and their individual physical needs must be supplied by techniques consistent with the economic and social characteristics of their environment as well as with its physical properties. Thus the limit of production of tropical soils in self-sufficient, democratic societies may be one thing, and the limit under a strongly controlled system designed for maximum production, quite another thing.

The great era of colonization during the fifteenth to the eighteenth centuries carried the Europeans and European ideas throughout most of the world. Slowly the forces of the new environments have broken down many of the old traditions and brought changes in techniques, laws, and customs to the point where the new races have reached a new individuality, sometimes in striking contrast to the old.

DEVELOPMENT OF CULTURAL SYSTEMS IN RESPECT TO SOIL GROUPS

Although it is impossible to divide the course of human history into neatly arranged and precisely defined categories, certain general and overlapping cultural periods are recognized in accordance with their

relative political and cultural contributions. Four of these are especially interesting to us and have been particularly important to our own civilization—the Egyptian, the classical (Greece and Rome), the Arabian, and the western (our own). Each of these cultural systems is characterized by more or less individual contributions to religion, art, and science. The previous systems seem to have progressed through periods of cultural growth, followed by periods of political expansion and mechanical development under city dominance, and finally declined, accompanied by a loss of ideals, depopulation, and cultural decadence. Causes have been sought for these great changes, and many explanations have been offered. Changes in climate, exhaustion of soils, and similar physical phenomena sometimes are given a large place in such explanations.

Evidence does exist for changes in climate. For example, it is known that prior to glacial times the Sahara Desert probably was greater and more terrible than it is today. Later, while much of Europe was covered with ice, this region became moist and more suitable for the growth of plants and animals. After the glaciers receded this temporary condition was changed, and the desert has returned nearly to its previous state (*121*). To what extent such changes have influenced the general course of human history during the past few thousand years it is impossible to say, but on the whole their influence would seem to be very greatly exaggerated by certain specialists in the physical sciences. The inadequacy of simple explanations of current human affairs should make us question their adequacy when applied to those of our ancestors.

The effects of soil exhaustion are especially difficult to evaluate. Soils are productive for plants only when correctly managed. Crop growth depends, therefore, upon both soil and husbandry, and a failure of either is sufficient to prevent production. Examples may be found of a temporary occupancy of land being terminated because of a failure of the soil. For example, irrigated soils may produce well for a few years and later become impregnated with salts and finally be abandoned. Soils subject to erosion under the generally prevailing type of management may, because of man's failure or inability to make the necessary adjustment, become so badly eroded as to be unfit for use for many years. Although there are many instances of such failures, their influences are relatively localized. There is no evidence of a general soil exhaustion and decline in productivity except as men have failed as husbandmen.

Furthermore, it must be understood clearly that even within a comparatively small region local soil types vary enormously in their inherent productivity for the prevailing type of farming adapted to the region as a whole. Only rarely are there large areas of soil uniformly productive and unbroken by patches of stony, hilly, or otherwise unsuitable land. In societies with increasing population, land suitable for farming may be unavailable to the new farmer. It may be impossible for him to purchase good land or otherwise obtain secure tenure. If he farms at all, his choice may lie between leasing good land at high rents for short periods and purchasing the poor land. Even on relatively poor land, the greater security of tenure may offset the advantage of better soil under a leasing or sharecropping system.

Thus, in the United States the best farms of a region may not always be on the best land. But the force of economic necessity sometimes has driven people to land so poor that failure was inevitable. Farms have been established on such areas of relatively unproductive soil, later to be abandoned. After such abandonment the land may be in a worse condition than it was originally, because of further depletion of fertility, erosion, or from other causes, until natural processes have had time to restore the soil. But this sequence should not be confused with the exhaustion of cropland; such land never was cropland in accordance with any likely economic pattern.

During the early periods of a culture, most of the people live close to the land. The soil satisfies nearly all of their requirements, and especially does it represent their principal security against the future. During this period the great fundamental ideas of the culture germinate, later to be expressed in distinctive music, architecture, literature, science, and philosophy. The main outlines of a cultural system apparently exist prior to the growth of great cities and mechanical development.

As each such system develops and becomes powerful—passes from the cultural stage to the civilization stage—it seeks to expand politically, first over the soil of its origin and later to other soils. By military forces, raised in the homeland, it seeks to subdue and control other peoples. For example, the Roman Empire, developed upon the red soils of the Mediterranean, later expanded to other landscapes in the east and to the north. Slaves were brought to Rome, and a new type of farming replaced the early type—the type that had produced the hardy Roman soldiers of the Punic Wars. The land was farmed by slaves, supervised by a bailiff, not by the owner, while the owner had other interests in the city and looked to the land for only a part of his income. The land became capital; the fruits of its production were diverted away from the farm to the city, Slowly the agriculture declined, and Rome was fed by grain grown by slaves or serfs at the fringes of the Empire. But more important, the sources of the virile blood that built the Roman Empire began to disappear, while a new group in the forests of northern Europe began to awaken. Roman agriculture became weakened, not from a failure of the soil itself, but because of a failure of men. With this breaking of the ties between men and soil came the weakening of the home race. Pressed by the vigor of a rising culture in the Near East and finally by the new races to the north, Rome was destroyed; or, perhaps more accurately, new trends were initiated.

Although theories are advanced from time to time that soil exhaustion has been directly responsible for the decline of ancient nations, it is likely that the reverse is more commonly true. The soils of Italy are probably producing more now than ever before. It was not the soil of Rome that failed, but the men.

This rise and fall of cultural systems is no simple matter. It is possible that there are no causes and that the whole of human history may be explained as some sort of mystic rhythm of birth, maturity, and death. But unless one completely rejects the idea that men have some responsibility for the direction of their destiny (and, fortunately,

not many do reject this idea), the mistakes of our ancestors need not be repeated.

Certain generalizations of importance to agriculture and to agricultural people seem to emerge.

For the most part, each of the great cultural systems of the past has been developed on a particular group of soils.

The endurance of a cultural system seems to have depended upon the ability of the people to achieve and maintain an adjustment of their techniques and laws to their soil.

For endurance, the people of each soil region must have political freedom to adapt their economic and social institutions to their own land.

If the new occupants of a soil do not, or cannot, adapt their social and legal institutions and their techniques to the new conditions, deterioration of the people, the soil, or both, may take place rapidly.

The final exhaustion of the land follows, not precedes, the exhaustion of the people. In a final effort, exploited people pass their suffering to the land.

Security of tenure in the land for the farmer through satisfactory leasing devices or ownership seems absolutely essential if our democracy, our people, and our soil are to endure.

Some societies have maintained a satisfactory relationship to their soil for a long time; others for a short time. It is impossible to forecast whether we shall be able to achieve such a relationship or how long it may endure.

Our country has many greatly contrasting soil regions with enormous variations in capabilities and necessities for use. With the proper balance of national solidarity and local autonomy this complexity can give rise to an even richer culture. Should we fail to recognize the special needs of the different regions, it might lead to destructive sectional conflicts.

THE DEVELOPMENT OF SOIL SCIENCE

During the course of human history, men have interested themselves deeply in the problems of agriculture, and slowly there has been built up a certain body of knowledge for dealing with them. An important part of this knowledge has been gained by direct observation and experience. Much was already available at the beginning of the Christian Era and was brought together by such writers as Varro, Pliny, Cato, and especially Columella. Even long years before this time, men were skilled in the use of manures and lime, crop rotations, irrigation, terracing, and similar techniques for the maintenance of soil productivity. Almost all of this knowledge was gained by the trial-and-error method over a very long period. The Chinese made a schematic soil map of their country about 42 centuries ago, as a basis for taxation and for the administration of agricultural affairs.

In each society the pursuit of knowledge for its own sake always has been an adventure of certain men having leisure and the requisite ability; however, the development of knowledge regarding soils and their use at any particular time or place, especially the applied phases of the subject, has been conditioned by the particular problems pressing for solution.

With the greater stability of Europe following the Treaty of Westphalia at the close of the Thirty Years' War (1648), populations increased rapidly. The soils of Europe were generally poor in both structure and fertility, and men became pessimistic about the future. In 1798 Malthus wrote his Essay on Population, developing the idea that population had much greater possibilities for increase than the food supply. The misery of the French peasants at the end of the eighteenth century stimulated thinkers in the physical sciences as well as in the fields of economics and politics. During this same period of unrest, out of which was born the concept of democracy, modern science developed rapidly in its application to agricultural problems as well as to those of industry and commerce.

The fact that the European students of economics and political science of this period did not foresee the ultimate rise of agricultural science, the great era of colonization just ahead, and the future importance of the black soils should not cause us to minimize the importance of their ideas (*237*). Yet, because of their limited geographic point of view, they did not conceive clearly the relationship between soil and the people. This could not be realized sufficiently until a world perspective became possible. Thus it was that for many years the problems of agriculture were attacked piecemeal and more or less separately by the physical scientist, the political scientist, and the economist. All were motivated by the same distress, but unfortunately each worked with his own tools, singly insufficient for the task. To what extent there is today a lack of mutual understanding and cooperation among these groups is left to the reader's own experience and imagination.

In the early eighteenth century Jethro Tull invented the grain drill and horse hoe and advocated cultivation, which led to the development of a system of crop rotations, including cultivated crops and legumes, known as the Norfolk system of Lord Townshend, replacing the old fallow system. Although based upon the theory that particles of soil entered the root directly, cultivation reduced weeds and improved yields. Where accompanied by marling, manuring, and careful husbandry, wheat yields increased to nearly 20 bushels to the acre on many farms.

Meanwhile chemistry was developing rapidly, especially after the perfection of the quantitative balance by the great Lavoisier. Despite the fact that he organized an experimental farm and devoted his time to the improvement of agriculture, he was led to the guillotine in 1794. The court simply observed to the defense, "France needs no scientists!" Despite handicaps, scientists continued their investigations at an accelerated rate. The old alchemistic theories concerning the principle of plant growth were beginning to melt away in the light of the new science. Acre yields of wheat rose from about 10 bushels to nearly double that during the 50 years after Lavoisier.

Field experimentation was begun in 1834, and shortly before the establishment of the famous Rothamsted Experimental Station in England (in 1843) the great German scientist, Justus von Liebig, had definitely stated the balance-sheet theory of plant nutrition: "The crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it in manure."

The reasonableness of Liebig's views and the power of his influence put an end to the alchemistic theories of plant growth. His theory received a serious blow with the discovery of bacteria, especially of those responsible for the fixation of atmospheric nitrogen, but it recovered and dominated much of the agricultural thinking in western Europe until recent years.

Although the theory was a great advance at the time, it probably did more to retard the development of soil science during the early part of this century than any other factor. In accordance with such a concept, the soil was considered a more or less static storage bin of plant nutrients. But soils are not static. Through the natural processes of development some materials are being lost; others are being added. Fresh minerals are being weathered. Some soils receive frequent deposits of alluvium. Others have new minerals added from beneath as the surface soil gradually erodes. Soils vary greatly in their responsiveness to management quite apart from variations in the supply of plant nutrients, important as these are. The theory singularly failed to recognize the dynamic nature of the relationship between the soil and the plant.

To man the important and significant attribute of the soil is its productivity for useful plants with the use of such techniques as he may employ. A productive soil must furnish compounds containing the required elements in proper balance for the normal growth and composition of those plants man requires for growth, health, and reproduction. This depends upon the nutrient status (fertility) and the physical condition (structure) of the soil. Both these qualities are important to plants and are themselves largely due to the activities of plants, animals, and micro-organisms. Thus the soil is primarily the medium for the growth of living things and is largely a product of living matter. The impossibility of setting up an adequate balance sheet for such a dynamic entity is obvious. Supplies of nutrients must be maintained. Some of our most productive soils require large applications of fertilizer. But the kinds and amounts are not determined by simple bookkeeping.

Since the scientists of western Europe were confined to a region having about the same general features of climate and vegetation, it is not surprising that they did not conceive the importance of these factors. The differences they saw were rather easily attributable to simple differences in slope, drainage, and parent rock. Yet, imperfect as they were, the new ideas stimulated agricultural science enormously. By the end of the nineteenth century, experimental fields had been established throughout western Europe. Chemical fertilizers began to be used with great success. By the beginning of the twentieth century, yields of grain had risen to over 30 bushels to the acre in England and Germany, nearly 300 percent since the death of Lavoisier. As far as western Europe was concerned, Liebig's theory worked.

Thus, in response to a definite and pressing need, western Europe developed a system of agriculture capable of producing far beyond the dreams or hopes of the eighteenth-century democrats. Even though these results were based upon an anormous amount of painstaking research, there still was no scientific system in soil science comparable to that in botany, chemistry, or mineralogy.

Russian Contributions to Soil Science

During the period of social upheaval in western Europe, Russia had remained essentially a medieval empire, controlled by a landed aristocracy. Although educational facilities were available to a very small part of the population, scientific work proceeded somewhat along the lines developing in western Europe, and many individuals rose to great eminence in biology, chemistry, and other fields. Soil science developed along entirely different lines. Whereas the soils of western Europe generally were unproductive unless carefully managed and heavily manured, many of those of Russia, notably the great areas of black soils (Chernozem), were highly fertile and had an ideal structure for the growth of the grains and grasses. Yields were frequently low, to be sure, but this was more a matter of poor tillage, poor seed, unstable climatic conditions, and the method of farming in small strips.

Russia was a vast country, containing within her boundaries many strongly contrasting landscapes and peoples. For the administration of such an empire, it was first necessary to determine of what it was composed. Investigations were necessary to solve problems of colonization and administration. In traveling over this vast area the intelligent observer could scarcely avoid noting the close relationship between climate, vegetation, and soils. Finally, about 1870, there sprung up a brilliant school of soil science under the leadership of Dokuchaiev, followed by Sibertsev, Glinka (fig. 2), Gedroiz, and others. In contrast to the agricultural chemists of western Europe, who studied specimens of soils in the laboratory, the Russian scientists first studied the soils in the field and supplemented these data with laboratory results. They noted that each soil was characterized by a distinct series of layers or horizons with particular characteristics, according to the nature of the landscape with which the soil had developed. Five principal factors were recognized as chiefly contributing to the properties of a soil: (1) Climate, (2) vegetation, (3) parent rock, (4) relief, and (5) age. Slope and parent rock were more or less passive and of local influence, whereas vegetation and climate were active factors responsible for regional characteristics and for the great soil belts running through the Empire.

From the concept that each soil had its individual character as a soil and its own geographic extension as the product of a particular environment, it was possible to erect a system of soil classification in which the various types of soil might be placed. As applied to great regions, the Russians developed such a system, based largely on those characteristics brought about by climate and vegetation, and many of the Russian terms, such as Podzol, Chernozem, and Solonetz, are now used by soil scientists everywhere. Since the boundaries between climatic belts and vegetative zones were nearly coincident in Russia, much weight was given the climatic factor. Modern investigations have shown that native vegetation is more important and that the influence of climate is partly indirect as a determinant of vegetation. The detailed investigations of soils necessary for elaborating the system to include local soil types significant to small units of operation—fields and farms—was not attempted on a significant scale by the early Russian scientists.

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The stimulation of the new Russian ideas was enormous. Already a large amount of information was available regarding soils in western Europe and the United States, but the data were scattered and unrelated. Analytical data and data on crop yields under various systems of management were abundant but of limited practical use until they had been related to definite soil types and could be expressed geographically. In the United States this problem had already been recognized and a beginning toward its solution made in 1899. Field techniques developed rapidly,[4] and by the close of the World War many counties distributed over the country had been investigated and mapped. Thus, in the United States and western Europe, there was a great deal of information, and the formulation of these data into a system founded upon the new principles has been rapid since the World War. That is, it has been rapid when measured in terms of previous accomplishments, but distressingly slow when measured in terms of present need.

Development in the United States

It should not be inferred that the researches of the Russian school were anywhere near complete or that the details of their science were entirely applicable to other countries having different soils and different problems. Because of the similarity of soils, it might be expected, however, that scientific methods that had been successful in western Europe would be equally successful in eastern United States. From a strictly scientific point of view, a great deal from both schools of thought is of tremendous value to us in the development of a body of knowledge for dealing with our own problems. Science knows no boundaries of time or place; no nation, race, or class has a monopoly on the world supply of intelligence or imagination. Yet the development of techniques in the applied sciences must be shaped considerably by the problems to be attacked, and these problems in our own country, if not unique, are at least our special responsibility.

Whereas problems of soil fertility and management occupied the chief attention of agricultural research institutions in Europe, they have received major consideration in only a very few of those in the United States. The availability of new lands in the Ohio and Mississippi Valleys, and finally in the West, relieved any serious pressure of population that developed in the East. Problems that arose in these areas could scarcely be resolved by the European methods, developed where intensive farming was economically feasible and based upon the unconscious assumption that soils differed but little in their capabilities for production. Certainly up to the close of the World War agriculture in the United States was eminently successful, if measured in terms of production or labor income, as compared to that of other nations.

Problems of land tenure, of stranded settlers, and soil depletion, which are serious now, became apparent several years ago. These and many others are parts of the critical problem of land utilization now upon us. Difficulties may be ahead, serious difficulties that might have been avoided. Some glaring mistakes have been made

[4] Without the splendid work in geology accomplished by a large group of distinguished American scientists, many of whom were with the U. S. Geological Survey, such progress would have been impossible. American soil science owes a great debt to F. W. Clarke, N. S. Shaler, C. R. Van Hise, F. Leverett, T. C. Chamberlain, W G McGee, and many others.

and some serious maladjustments have gone long unmended. We could have done better, but by and large, when compared to those of other nations, our soil resources have been used effectively for their principal function—to furnish homes for the people. Recent changes in population and in industry, the growth of great cities, the social and economic influences of the World War—these forces make new adjustments essential. Certainly the answers to these problems could not be expected before the problems themselves were recognized.

Many of these land problems pressing for solution are distinctly of a regional character. This had been recognized by a few American soil scientists 40 years ago. Contemporary with the Russian school, Hilgard of the United States came to somewhat similar conclusions regarding the correspondence among soil regions, biological regions, and climatic belts (*164*). He left a large heritage of data and observations, and, except for nomenclature, his textbook (1906) is still perhaps the best volume on general soil science written by an American. Perhaps Hilgard (fig. 3) came a little too early; whatever the reason, his ideas were slow in taking root.[5] Hopkins in Illinois,[6] King in Wisconsin (fig. 4), and several others have achieved success locally, using the European methods, especially in areas having soils somewhat similar to those in Europe. But many of the problems that seem of great importance now were not realized by people generally until the late 1920's.

Milton Whitney (fig. 5) and his coworkers in the Department of Agriculture began calling attention to the failure of the balance-sheet theory, as applied in the United States, about 1900. A few years later Curtis F. Marbut began his researches in soil morphology and soil geography. Inspired by an intimate knowledge of the contrasting landscapes of the United States and realizing the basic principles underlying any solution of the growing agricultural problem, he seized on the new tools developed by the Russian school and pushed his own researches vigorously along the lines of a new concept. Through these researches, and especially through the influence of his radiant personality, a system of soil classification for the United States was developed.

This does not mean that nothing had been done previously. As a matter of fact, a great deal had been done. The fertilizer industry had grown rapidly, guided by research. Lime for legumes was being used at an increasing rate, and methods for inoculating them with the proper bacteria were developed. Many other techniques were greatly improved. But the data were scattered, incomplete, and too unorganized to answer accurately practical questions as to what techniques should be applied to particular farms and to what degree.

The development of a system of soil science made possible the organization of these data and their utilization in solving agricultural problems. At the same time the inadequacy of our knowledge in terms of the problems to be solved became clearly apparent for the

[5] Another American, C. F. Vanderford, published an obscure bulletin in 1897, The Soils of Tennessee (*438*), in which he called attention to this intimate relationship between soil and plant and anticipated many of the modern views in soil science, especially those respecting soil erosion. Unfortunately his publication received little attention.

[6] For a picture of Dr. Hopkins, see p. 568.

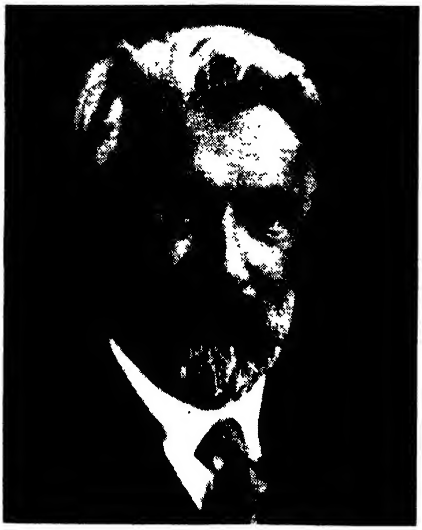

FIG. 2.—Konstantin Dmitrievich Glinka (1867-1927) was for many years the leader of the Dokuchaev school of pedology. The publication of his great textbook in 1914, Die Typen der Bodenbildung, and the translation in English in 1927 as The Great Soil Groups of the World and Their Development, first made the work of this school widely known to western European and American soil scientists.

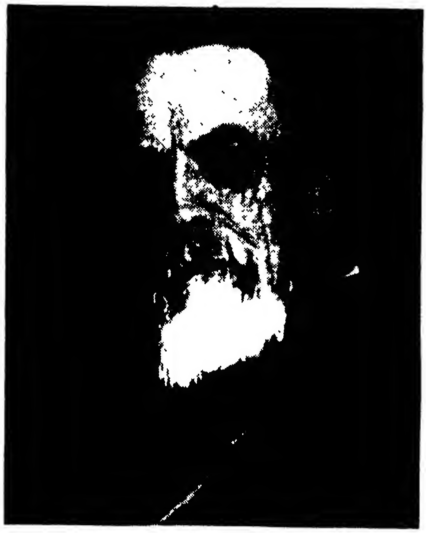

FIGURE 3.—Eugene Waldemar Hilgard (1833–1916), an early pioneer in soil science in the United States, for many years connected with the University of California. He is noted especially for his studies of the relationship between soils and plant associations, of salty soils, and of the irrigation of soils in arid regions. His great textbook, Soils, is classic.

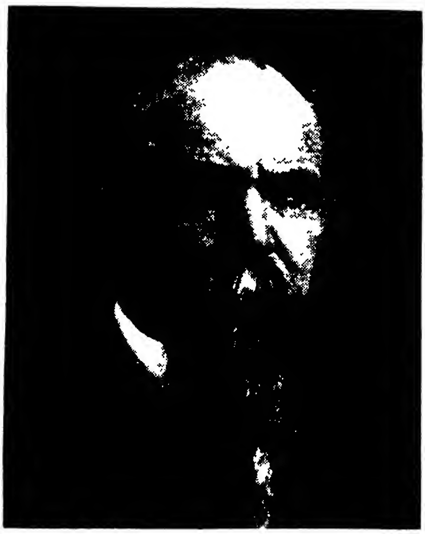

FIGURE 4.—Franklin Hiram King (1848–1911), for many years connected with the University of Wisconsin and noted especially for his work on the physical properties of soils and the relationship of these properties to the use of the soil.

FIGURE 5.—Milton Whitney (1860–1927), for many years chief of the U. S. Bureau of Soils. He began the soil survey work in the United States and initiated many other soil researches which laid the foundation for our present concepts of soil.

first time. At his death in 1935, Marbut left us the foundations for a system of soil science. The staggering task of developing this system in accordance with our national need is still ahead.

FUTURE DEVELOPMENT

Agricultural science as a whole has developed remarkably in the United States, but in a piecemeal fashion. Especially there has been only a beginning in the application of soil science to problems of agriculture and the people on the land, and already there is danger of the application attempting to go beyond the basis of fact that must support it. In part this is due to the late development and recognition of critical agricultural problems in the United States, especially in respect to the land.

Another important factor may be the extreme specialization in the research field. As scientists become more and more specialized and objectives more narrow, coordination of attack in applied fields becomes more difficult. The highly trained specialists may tend to become segregated, cloistered, and to lose their contact with the land and the people who make their living from it. Only specimens of soils may be brought into the laboratory. A soil in the field or in the garden contains moisture, bacteria, and living roots. It is responsive to the rain and the sun. When man uses it, he uses it in its whole environment. Studies of the soil must be made in that environment, which is in the field. Yet without the careful work of the chemist, the physicist and the biologist in the laboratory, field studies are likely to be superficial and illusive. Both laboratory and field investigations are needed, not as ends in themselves but as contributing to the common objective of determining the highest capabilities of our soils in a system of permanent agriculture.

American agriculture consists of many agricultures. Problems relating to the whole can be stated only in the most general terms. Reference to particular regions, and above all to individual farms, must be based on specific knowledge. What is learned in one region may have little application to another. What is a desirable course of action on one farm may be ruinous on another. Especially in the American democracy, the individual farm is important as well as the group or region. Any regional adjustments must go along with the individual adjustments. Thus soil science in the United States must be detailed in its application, must be inspired by an understanding of the detailed problems, and at the same time must recognize regional groups of soils and determine their characteristics and limitations. Both are important; both types of data are essential to any solution of our agricultural problems. Too many of the ideas we have now are generalized from too few particulars and are inspired more by books than by the land; and too many of our books are written simply from other books, not from studies of actual soils and the problems of the people who live on them.

In certain parts of the country a measurable beginning has been made in the development of a body of scientific knowledge regarding the soil; in other parts only a little is known. Fortunately the spectacular problem of soil erosion has lately received some public attention. Yet the broad fundamental problem of the relationship between the

soil and the people who use it, of which the question of erosion is only one part, is less generally realized. Certainly problems of rural land use, of rural health, of rural tenancy, of rural taxation, of rural schools, and many others are realized, and keenly so, by many of our people. What is not understood fully is that these are all intimately associated with the same fundamental problem—the relationship of the soil to the people living on it. Several of these rural problems are and should be studied from the point of view of economics and sociology, but such an approach by itself is, in the very nature of things, only one step, and more or less superficial so long as it stands alone.

Man lives and must work to supply his needs in an environment that is both social and physicial. All the land in the United States could be made to produce crops, and there is none that will produce without labor. What land will be used at any moment, with what techniques, and with what success, depends upon the social and economic frame of reference within which people work, as well as upon the physical environment. Every time the economic and social conditions change, a new physical problem is created, and each time a new technique is developed, a new economic question appears. New problems for both the physical scientist and the social scientist will arise as long as society changes. And when society ceases to change, the end will have come. Students of agriculture are coming to this realization. Soil studies in an economic vacuum and economic studies in a physical vacuum compete for uselessness as contributions to a solution of our land problems.

There is more serious thinking regarding our soil problems today than ever before, and the new American soil science is developing. It is still too early to prophesy how rapidly this development will proceed—whether it will be able to make a real and substantial contribution to the solution of our present problems, or whether they must wait for a future generation. Some of them are serious and may not wait too patiently. The young soil scientist must keep his books, study them, and learn from the past. But above all, may he seek his inspiration from these human problems on the soil.

SOIL *is a complex thing produced by many forces acting together. What are the forces that produce soil? Can a soil be said to have a life history like that of an organism? Why are there such marked differences between the soils in different regions? What is a soil profile, and what does it tell about the soil? What is the significance of the color, the texture, and the structure of a soil? Such questions are discussed in this article.*

The Physical Nature of Soil

By T. D. Rice *and* L. T. Alexander [1]

MANY physical properties of the soil are observable without the aid of instruments. It was early recognized, for instance, that some soils were mellow and easily tilled, that others were sandy and blew readily, and that still others turned up in clods if plowed too wet. Until relatively recent times such observations were not treated scientifically. Even now only a beginning has been made in the study of the physical properties of the soil in relation to plant growth.

The physical as well as the chemical and biological processes—known collectively as the soil-forming process—are caused and controlled by such factors of the environment as climate, vegetation, and relief. These forces are complex, each interacting with the others, and they are slowly but constantly changing. Under the influence of these changing forces and conditions, the soil must be a complex substance, itself undergoing constant change and never reaching a static condition. It does, however, have a life history, passing slowly through stages which can be considered as youth and maturity, and in some cases even reaching old age.

Soils begin their history with the accumulation or exposure of finely divided, weathered rock materials. The next step, often coincidental with the first, is the introduction of living organisms and the beginning of the constructive phases of the soil-forming process. As the process operates upon the rock materials, changes are slowly brought about in the surface layers which, if allowed to continue for a long time, will make those layers very different from the parent material. The changed portion, which is regarded as the true soil, may vary in

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thickness from a mere film to several feet. The character and thickness of the soil thus formed depends on the intensity of the soil-forming processes, the time during which they have acted, and the resistance of the parent material to change. When a soil has developed certain definite characteristics it is said to be a mature or a well-developed soil.

At any stage of its history a soil may be affected by mechanical agencies. The surface layer may be wholly or partly removed by erosion, exposing the material beneath. The soil-making processes then begin anew on the material thus brought under their influence. Whether this change is detrimental or beneficial to the growth of plants depends on the rate of removal and on the supply of nutrient elements in the newly formed surface layer. When man uses the soil he upsets the balance maintained by normal erosion, forcing the soil to higher productivity or into a state of decadence.

It should be emphasized that normal erosion is beneficial to the soil and should not be confused with accelerated erosion, which is brought about by misuse of the land. Normal erosion may be pictured as being the removal of soil from the surface at the same rate as soil-forming processes penetrate downward, so that a constant depth of soil is maintained.

Since the forces that are building up, changing, or destroying the soil are not uniform over large areas of the earth's surface, soils show a corresponding lack of uniformity. A particular combination of conditions will give the soil of a region definite characteristics.

The character and quantity of the vegetation a soil supports are due to its physical, chemical, and biological characteristics, which have been developed by the soil-forming process. Not all soils are productive of plants useful to man, and not all the constituents of the soil promote the growth of useful vegetation. Some plants will thrive only where the most favorable conditions exist in the soil; others have adapted themselves to tolerate chemical and physical conditions that would destroy ordinary plants.

THE SOIL PROFILE

Within recent years a great increase in our knowledge of the physical properties of soils and their influence on plant growth has been obtained by studying the soil in the field, in its undisturbed condition. If a hole is dug in any well-drained upland soil, there can be seen on its walls a series of horizontal layers of soil of varying thickness. The layers are called horizons, and they differ from one another more or less sharply in such properties as color, texture, and structure. Occasionally there are areas of such distinctive constituents as compounds of lime or iron. The succession of horizons from the surface down to and including the parent material is called the soil profile.

Investigators refer to the separate horizons of the soil profile by the letters A, B, and C. The A horizon includes the upper part of the profile, in which life is most active and abundant. It may be marked almost wholly by an accumulation of organic matter, as in grassland soils, or it may be characterized by an accumulation of organic matter at the immediate surface and the removal of certain mineral constituents just below, as in normal forested soils. Commonly the plowed

layer lies within the A horizon and includes most of it. The texture of the A horizon is used in establishing the soil-type names used by soil surveyors, such as Miami silt loam in Indiana. The B horizon is marked by deeper colors and heavier texture in normal soils of humid regions. The A and B horizons together constitute the solum, or true soil. The C horizon is the unconsolidated material below

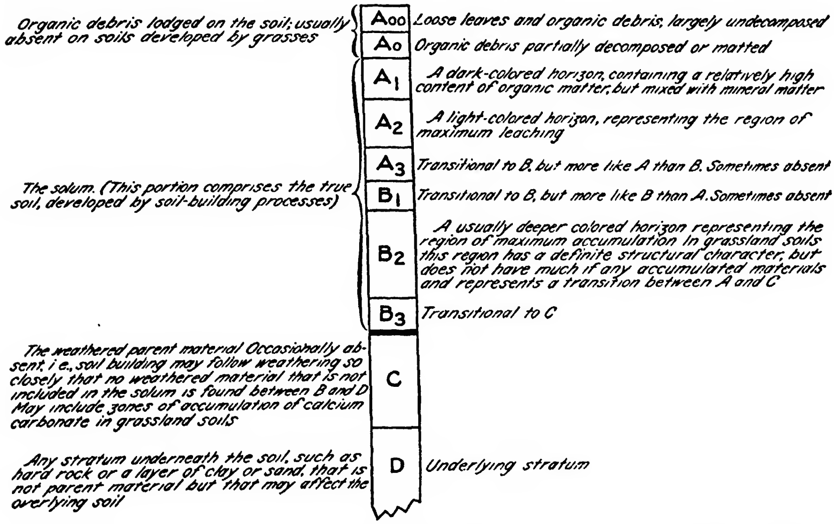


FIGURE 1.—A hypothetical soil profile having the principal horizons. No one soil would be expected to have all these horizons well-developed, but every soil has some of them. It will be noted that horizon B may or may not have an accumulation of clay.

the solum, usually referred to as the parent material. A diagram of a hypothetical soil profile is presented in figure 1.

The development of a soil profile with its particular horizons is not a matter of chance. Mature soils developed over the same parent rock under the influence of similar external conditions of climate, vegetation, and relief will present horizons of similar sequence and thickness possessing similar characteristics. Soils developed from similar materials that have been acted upon by environmental factors that are different in kind or intensity will have different profiles. The great climatic belts of the world, with their resulting types of vegetation, have corresponding soil belts. It is clear, therefore, from a study of profiles from various soil regions, that the characteristic horizons are produced by definite forces acting upon soil material during longer or shorter periods of time. Examples of a number of profiles selected to illustrate some of the great soil groups are shown in figure 2.

Over a large part of the United States soil horizons have not reached their fullest development. In soils such as those along the Mississippi River this is due to the short period during which the soil-forming processes have been operating on the alluvial materials, which are water-deposited. Lack of full development may be due to local

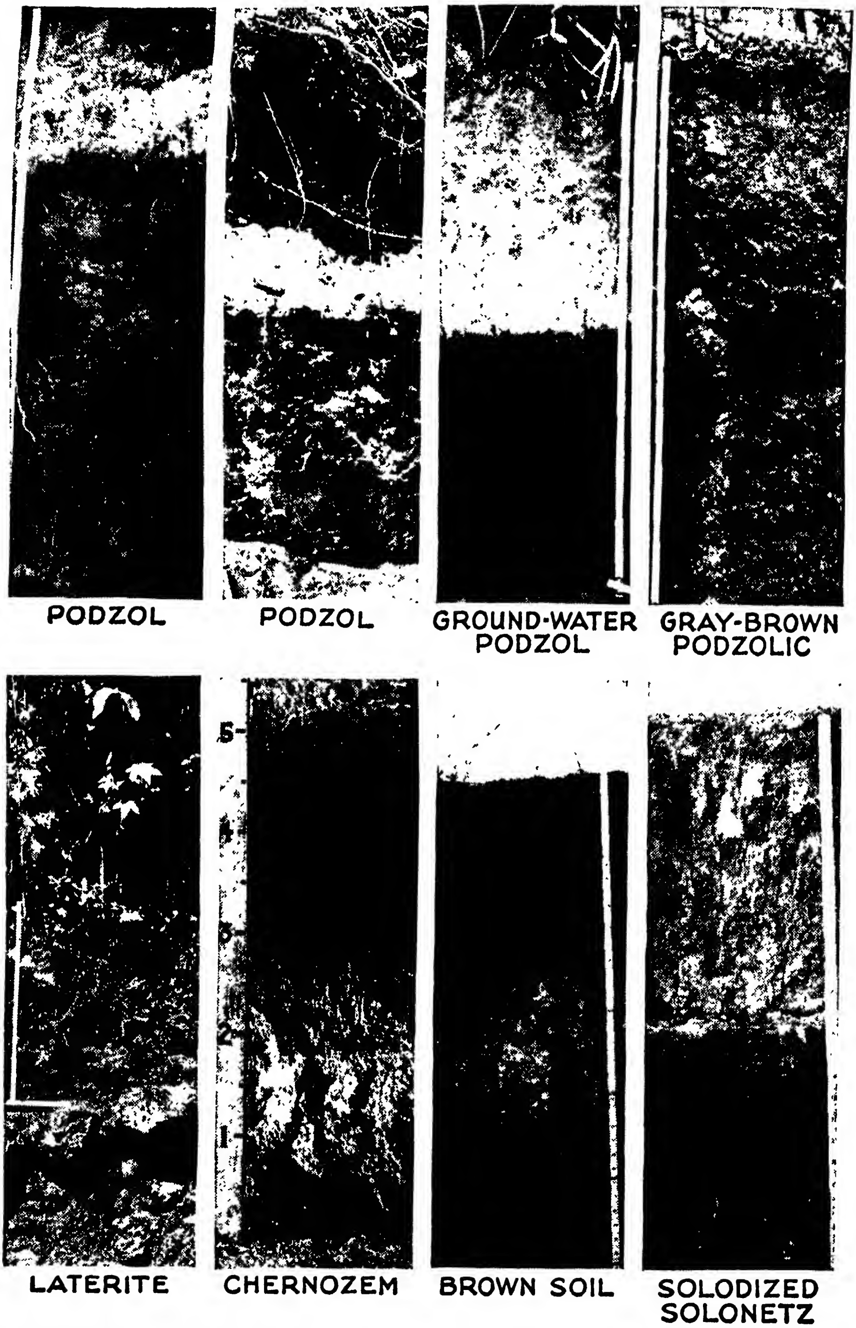


FIGURE 2.—Eight soil profiles. A discussion of these soils will be found in the article Formation of Soil (p. 948).

conditions of poor drainage or excessive erosion. Abnormal profiles may also occur because the land is so level that there is no normal erosion.

SOLID, LIQUID, AND GASEOUS COMPONENTS OF THE SOIL

The soil horizons themselves are made up of materials in three different states—solid, liquid, and gaseous. Proper proportions of each of these constituents are necessary if the soil is to be a good medium for the growth of plants.

The solid portion of the soil is composed of several kinds of matter that may be broadly divided into organic and inorganic. The inorganic portion is the part that is left from the decomposition of the parent rock by the chemical and mechanical processes of weathering, while the organic portion consists of dead and living plants and animals and their products.

The inorganic portion of the solid material is variable in size, ranging from gravel and stones down to colloidal particles of clay with diameters of less than one one-hundred-thousandth of an inch. The proportions of coarse, fine, and medium particles determine the texture of the soil. The coarse and medium materials are comparatively inactive, serving mainly as a supporting framework of the rest of the soil. A much more complicated function is served by the fine or clay fraction, the chief component of which is colloidal [2] in nature. It serves as the bank in which plant nutrients may be placed for future use and from which they may be withdrawn when the plant needs them. With good colloids the capacity for storage is great; with poor ones it is small. The kind and quantity of colloidal material largely determines how much water can be held in the soil, especially in regions where rainfall is limited.

The organic portion of the soil material consists of both living and dead matter. Plant roots, fungi, bacteria, worms, insects, and rodents comprise the bulk of the living matter, and the remains of plants and animals, together with the products of their decay, make up the dead portion. The residue from the decay of these organic bodies is largely colloidal and, like the inorganic colloid, plays an important part in holding plant nutrients and water.

The liquid portion of the soil, called the soil solution, consists of water containing varying quantities of dissolved mineral matter, carbon dioxide, and oxygen. While it seems relatively simple, it is one of the most complex components of the soil, and perhaps the one about which our knowledge is most incomplete, owing to our inability to study the soil solution in place and lack of a satisfactory method of separating it from the solid portion of the soil for chemical and physical analyses. The soil solution is the medium through which the mineral elements, nitrogen, water, and perhaps some carbon dioxide, enter the plant. If the balance between the various constituents of this liquid is not favorable, the soil is not a good medium for plant growth.

The third component, the gaseous portion of the soil, is also very important. It is well known that if a soil becomes waterlogged it

[2] See the article General Chemistry of the Soil for a discussion of the nature and properties of colloidal materials.

sours, and normal upland plants cease to grow in it. In this case, water has almost completely replaced the air in the soil, depriving the plant roots and the aerobic soil micro-organisms of the oxygen of the air, which is essential to their existence. The proportional part of a soil occupied by gas varies with the amount of water present, since they replace each other. The total amount of space in a soil that is occupied by air and water together is usually referred to as pore space.

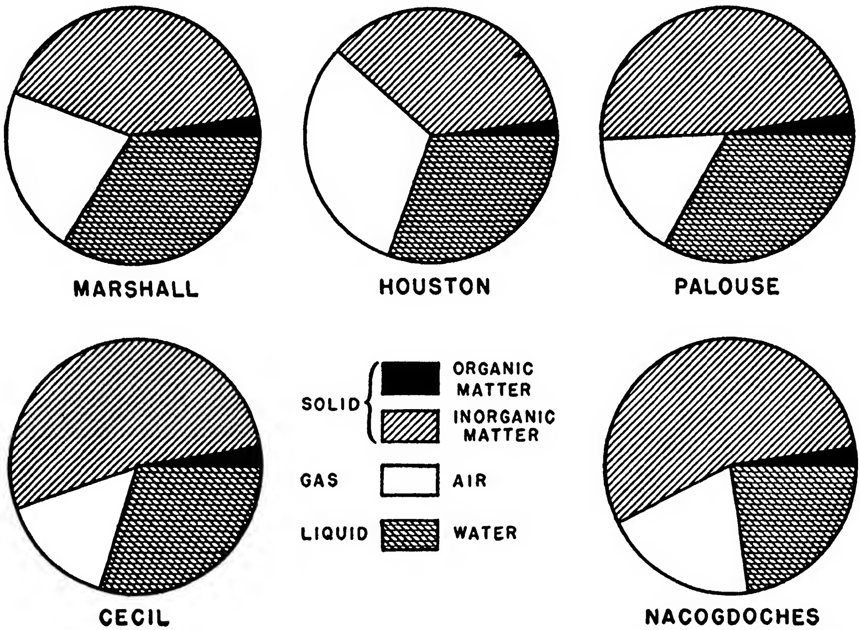


FIGURE 3.—Proportions of various constituents of soils by volume at comparable moisture contents.

If the soil is not porous enough, it is difficult or impossible for plant roots to penetrate it, to secure an anchorage, and to obtain nutrients and water. If it is too porous it will not retain enough water to support good plant growth.

The relative proportions of these several constituents in a few typical soil samples are shown graphically in figure 3. The illustrations are for soils taken to average plowing depth.

COLOR

The color of a soil is perhaps its most obvious characteristic, and in connection with structure and texture it forms the basis for differentiating soil horizons. Color in itself is of minor importance, but it often serves as an indicator of other soil conditions that are extremely important.

In general, dark-brown to black soils are regarded as being the most productive. This association of dark color with productivity is well-founded, but it does not invariably hold. Black or brown coloring is usually due to the high content of humus and is thus associated

with a favorable structure and adequate supplies of nutrients such as calcium and nitrogen. Rarely, black color may be due to a high content of some mineral. Dark colors are also associated with inadequate drainage in humid regions, so that color in itself cannot be taken as a final measure of the productivity of the land.

In general, red or reddish-brown soils are less fertile than black or dark-brown but more productive than yellow, gray, or white soils. Red soils owe their color largely to compounds of iron known as unhydrated iron oxides. Since this form of iron does not continue to exist in poorly drained soils, red colors usually indicate good drainage and good aeration. This is almost invariably true of the red soils of the Southern States. In some instances, however, the red color of the soil is inherited from the parent material and is not due to soil-forming processes.

Yellow colors in soils are thought to be due to hydrated iron oxides. Many yellow soils are imperfectly drained; others seem to have acquired their color from a previous condition of restricted drainage. Yellow soils have low inherent productiveness.

Gray colors in soils may be due to lack of sufficient oxygen or to low contents of organic matter and iron. Soils containing reduced compounds of iron are commonly gray or bluish gray and may be mottled with yellow or rusty brown if the water table fluctuates. Such soils normally support a very specialized or stunted vegetation. In some soils of cool, humid regions thorough leaching of iron compounds and organic matter has resulted in a gray color. In extremely arid regions the thin cover of plants does not produce enough organic matter to give the soil a darker color. Accumulations of calcium carbonate and other salts ("alkali") may leave the soil gray, or even white. White soils occasionally occur in humid regions, and whether dry or wet, they seem to be the least fertile of all.

TEXTURE

The mineral particles of the soil are classified according to size into three principal groups, which are called sand, silt, and clay. The particle sizes in each of the groups range between certain limits, which have been arbitrarily fixed at diameters of 2 to 0.05 mm for sand, 0.05 to 0.002 mm for silt, and less than 0.002 mm for clay. Sand grains feel gritty to the fingers and can be distinguished without difficulty by the unaided eye. Silt, barely visible to the naked eye, has the appearance and feel of flour. The individual particles of the clay fraction are not distinguishable by the eye, and a large proportion of them are too small to be seen under the microscope. It is this fraction that makes soils sticky when wet.

Varying proportions of these particles of different sizes determine our classes of soils, or what is known as soil texture. The principal classes in the order of the increasing content of silt and clay are as follows: Sand, loamy sand, sandy loam, silt loam, clay loam, and clay. In addition, there are recognized textures that have been named because of a particular size of the coarser particles, such as fine sand, loamy fine sand, fine sandy loam, coarse sandy loam, and gravelly loam. Variations within the clay and clay loam classes are indicated as sandy clay, silty clay, sandy clay loam, and silty clay loam. A

soil containing a sufficient content of stone to influence its use may have the term stony added to its designation, as stony loam or stony clay loam.

Figure 4 shows the proportions of sand, silt, and clay in five typical soils of different textures. In mechanical analysis, by which these proportions are determined, the clay fraction and part of the silt is washed from the sand on a sieve which will not allow any of the sand to pass. The remainder of the silt is then sieved from the sand. The amount of clay present is determined by measuring its rate of fall in still water.

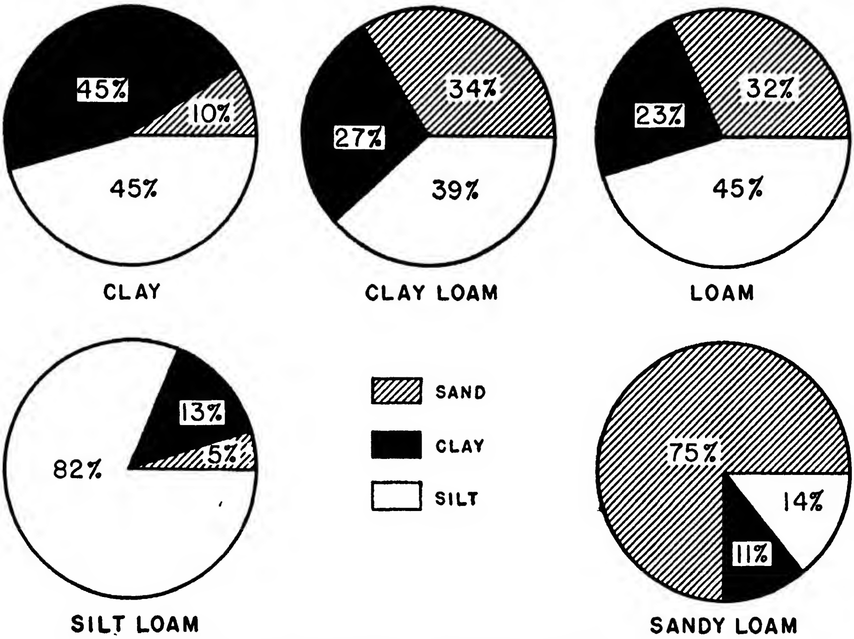


FIGURE 4.—Percent of sand, silt, and clay in soils of various textures.

Texture influences plant growth through its effect on the physical condition of the soil and its influence on the supply of mineral elements. The structure or the degree of granulation of the soil, which will be discussed below, depends partly upon texture. Physical properties, such as absorption and retention of moisture and aeration, are affected by it. Coarse sands are usually too well drained, and heavy clay soils of temperate regions often lack adequate aeration. Soils of finer texture (silt loams and clays as compared with sands and sandy loams) contain a much higher proportion of fine particles, which decompose more rapidly to release plant nutrients, such as potassium. Finely textured soils also have a larger capacity for the storage of available nutrients, as has already been pointed out.

STRUCTURE

Whereas texture refers to the individual soil grains, structure refers to the arrangement of those grains within the soil mass. The individual grains are commonly held together in aggregates of different sizes and

shapes, although soils do occur in which there is no structure. The size, shape, and stability of such aggregates have a marked influence on the productivity of cultivated soils.

The maintenance of favorable structure in cultivated soils is just as important to the farmer as is the preservation of soil fertility. Farmers are familiar with the results of plowing heavy clay soils when they are wet. The clods formed may interfere with tillage and crop production for many years. Recently, farmers in the Great Plains have

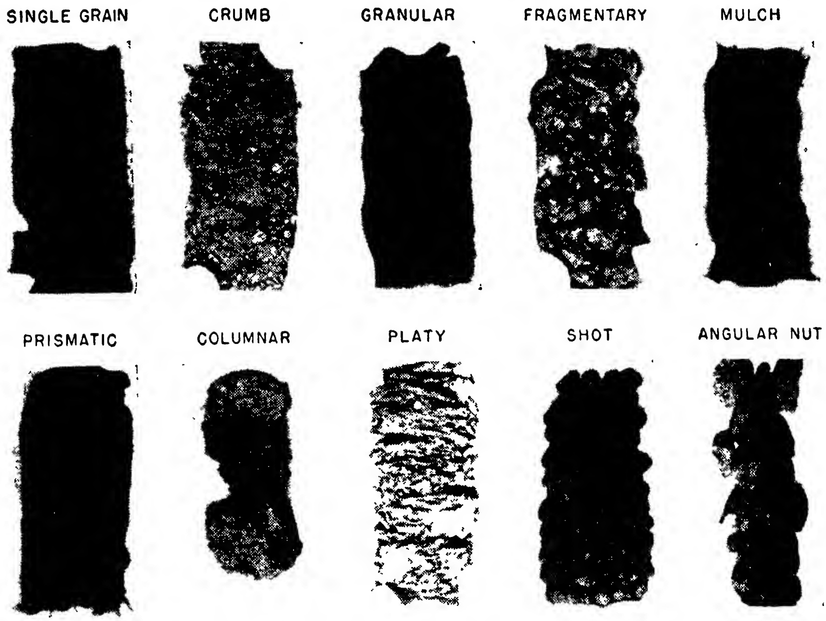


FIGURE 5.—Several important types of soil structure. All of these structural types are produced through the operation of soil-building processes, except that the single grain and fragmentary may be developed or may be inherited from the parent material. (About one-fourth actual size.)

faced the problem of maintaining a rough, finely cloddy surface on their soils so as to prevent blowing. In humid regions the presence of a heavy, impervious B horizon in the soils of sloping lands results in serious erosion which would not occur if the B horizon had a granular or nut structure readily penetrated by water. Many more examples could be given to emphasize the practical importance of soil structure. The structure of soil horizons largely determines the ease with which plant roots can penetrate, the rates of absorption and movement of water, the tilth and mellowness at any given time, and the resistance of the soil to erosion by wind or water. Some of the more common types of soil structure are shown in figure 5.

Structure is of extreme importance to those engaged in the scientific study and classification of soils as well as to the farmer.

The granular and crumb structures are the most favorable for the growth of crop plants. Such types of structure normally develop un-

der grass or other close-growing vegetation, but crumb structure may be found in soil under forest growth, particularly where there is a dense ground cover. In ordinary farm practice, the development and maintenance of favorable soil structure is associated with the growing of grasses and legumes. Such crops have not held as important a place in our rotations as they deserve, but they will become more important as times goes on and the functions of soil structure in soil productivity are more fully realized.

WATER is no less important to the soil than to living things. How is it held in the soil? In what forms is it found? What laws govern its movement, up, down, and sidewise? How much of the water in the soil is available for the use of plants, and how is it measured? From the standpoint of moisture conservation, is it good or bad to maintain a dust mulch? How should sticky soils be managed? These are some of the questions discussed in this article.

Water Relations of Soils

By L. B. Olmstead *and* W. O. Smith[1]

AMONG the important physical properties of soils are those which enable the soil to receive, hold, and transmit water for the use of crops. These physical properties and their water relations will be considered in connection with three distinct soil zones: (1) The surface, through which water may enter and leave the soil body; (2) the root zone, in which plants obtain their nutrients; and (3) the section lying below the root zone, which is of concern in this discussion only as it affects the moisture relations of the other two regions.

The soil is a porous body made up of discrete particles of irregular shapes and various sizes. The spaces between these particles form a complicated network of connected cavities of almost every conceivable shape and size, from those too large for the effective operation of capillary forces to those too small to be seen with a microscope. This assemblage of cavities, called the pore space, is filled with water and air, both vital to ordinary crop plants. When the pore space is filled with water it is said to be saturated; when it is partly filled with air it is unsaturated. The shape and size of portions of the pore assemblage may change through forces exerted by the water bodies and the swelling and shrinking of the colloid portion,[2] which coats the sand and silt particles and collects into aggregates.

Water is held in the soil with varying degrees of freedom. That occupying the larger cavities moves freely, evaporates readily, and freezes at practically the same temperature as water in an open tank. But a small portion of water is held so firmly by physical and chemical

[1] L. B. Olmstead is Physicist, and W. O. Smith is Associate Physicist, Soil Chemistry and Physics Research Division, Bureau of Chemistry and Soils.

[2] The nature and properties of colloidal materials are discussed in the article General Chemistry of the Soil, p. 911.

forces that it remains unfrozen at a temperature far below the ordinary melting point of ice and does not evaporate until heated nearly to the usual boiling point. Water is physically bound in soils in all intermediate stages between these two extremes. In all soils some water is held so strongly that plant roots cannot extract it. Most of this water carries in solution varying concentrations of the products of decomposition of the soil materials, soluble products from the air, and other substances such as lime and fertilizers. In this discussion these varying solutions are all included in the term water.

THE MOVEMENT OF SOIL WATER

The movement of water in soils is caused by one or more of three physical agents. One is gravity, which always acts downward and therefore causes free water to seek a lower level. Another agent is heat, which vaporizes the water and enables it to move with, or diffuse through, the soil air. This vapor may condense in another part of the pore space or finally escape into the atmosphere. The third and most active agent in the movement of soil water is capillary tension, the force that causes kerosene to rise in a lamp wick and ink to flow into a blotter. In order to present a clear picture of the behavior of soil water, it will be necessary to explain how capillary tension, or capillarity, functions.

There are two kinds of water surfaces in the soil, one in contact with soil grains and the other in contact with the air. The forces at these two surfaces behave very differently. At the water-soil surface there is a strong force of attraction, which causes the water to spread out into a film upon the soil surface. The water-air surface, or interface, acts like a stretched skin or rubber membrane that tends to reduce the surface to the smallest possible area. Free drops of water are spherical because a sphere is the solid form having the smallest surface area in relation to its volume. The tension in a water-air interface produces a pressure upon a free drop of water but a pull upon the water in a capillary tube, the curvature of the interface being concave toward the water in the drop and convex toward the water in the tube.

How capillary forces operate in soils is illustrated in figure 1, which represents a greatly magnified cross section of a small soil granule made up of impervious grains in contact with water beneath it. When water first touches the lowest soil grains, water films quickly spread over these and the adjacent ones. In the capillary pore spaces where these films join, the water is under tension and therefore rises. Water now comes in contact with additional grains, which in turn become covered with water films, and an additional lift of water into the adjacent capillary spaces follows. In this manner capillary rise continues until the tensions of the capillary water surfaces in the larger pores are unable to lift the water any higher against gravity.

Water rises to the greatest heights in the smallest capillaries. In a sand whose grains are larger than 0.1 inch in diameter, practically no capillary rise can occur. In a medium sand, ranging in size from 0.5 to 0.25 mm (approximately 0.02 to 0.01 inch) in diameter, the maximum possible rise may be less than 1 foot. Water may creep downward over the surfaces of successive soil grains without the pores

being filled with water, but practically no capillary water flows upward unless essential parts of the pore assemblages fill with a continuous body of water.

The number of continuous paths fine enough to lift water decreases as the capillary water front rises. Finally, the weight of the water to

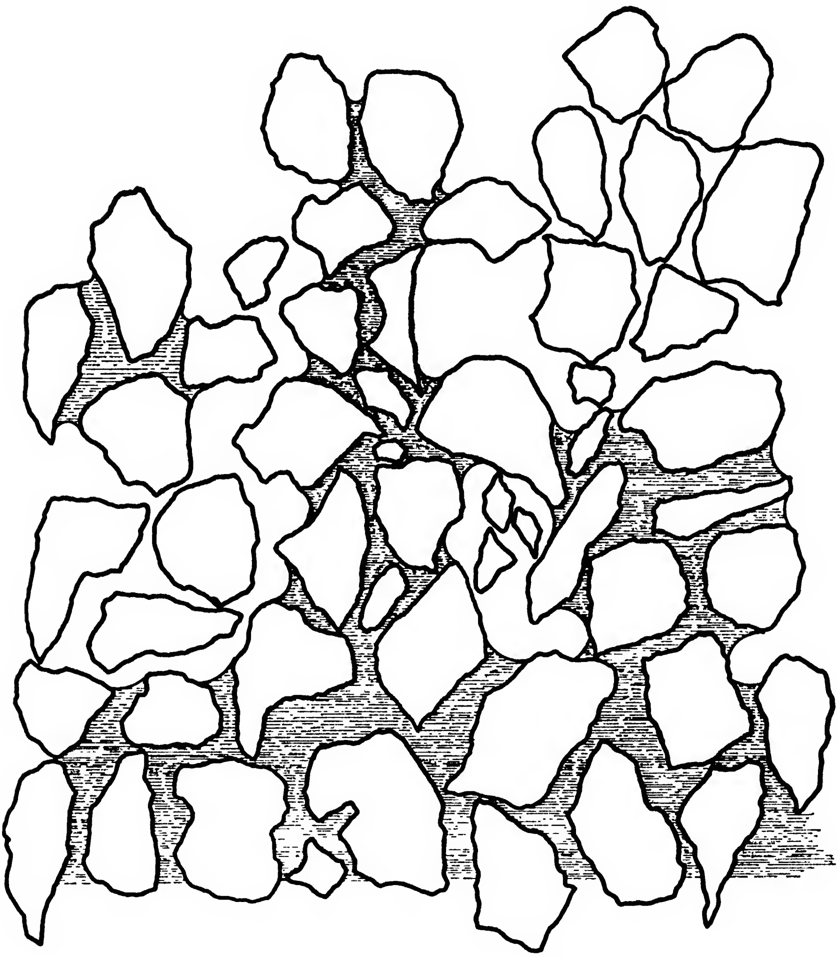


FIGURE 1.—Capillary rise from a saturated soil layer.

be lifted and the resistance to flow become so great that capillary rise practically ceases. The initial rise is less rapid in compact clay soils than in sandy ones, because the finer channels of the clays, further reduced by swelling, offer a higher resistance to the flow of water through them. However, the lifting power of the fine capillaries is so much greater that the clays ultimately achieve the higher rise of water. Compact soils composed of very fine sand and silt possess the most favorable pore assemblage for rapid and high lift of water.

Figure 2 represents the capillary water system when no water table is present. The condition shown is an unstable one. The water-air interfaces on the right, with the higher curvatures, exert a greater pull upon the water body than the flatter capillary surfaces on the left. Water, therefore, will move from left to right until the capillary sur-

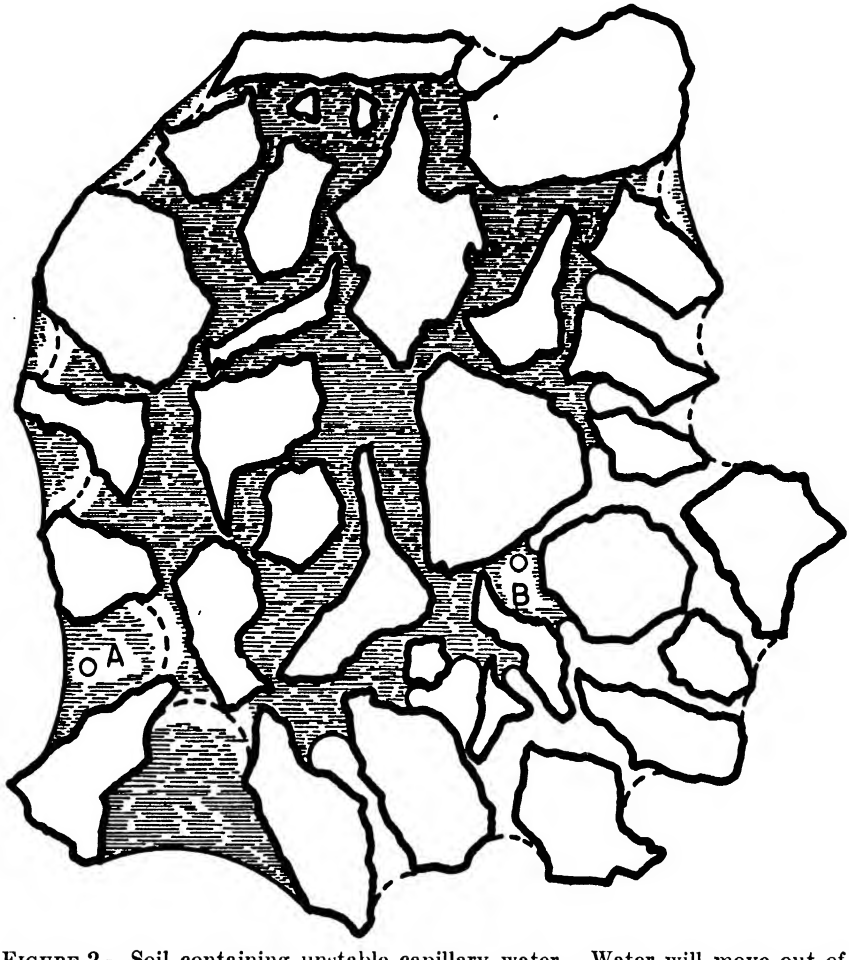


FIGURE 2.—Soil containing unstable capillary water. Water will move out of region A into region B and will eventually fill the void spaces as far as the dotted line.

faces occupy the spaces between the dotted lines. Except for a small effect from the pull of gravity, all capillary surfaces will then have the same curvature, provided thay are all connected through a continuous body of water. Since all the capillary surfaces of figure 2 face and pull outward, the water occupying the pore assemblage is not under compression, but under reduced pressure or tension—a capillary tension. This tension pulls the soil grains together and helps to hold them in a granule.

When the irregular-shaped pore cavities empty or fill, the flow of water usually is not steady but occurs in sudden jumps, or steps. This is due to the fact that when the water-air surfaces occupy the waistlike constrictions of the pore assemblages, they have a greater lifting power than when they occupy the larger cavities above or below. Water may rise slowly in a barrel-shaped capillary until it passes the bulge in the middle and then suddenly rise to the top.

There is still much to be learned about the movement of capillary water in soils. For instance, it is not known just why capillary water often moves so slowly from a wet soil layer into a dry one. Some of the water, no doubt, moves by diffusion caused by the random motion of the water molecules. Some capillary movement arises from the condensation of water vapor just beyond the capillary water fringe. If the wedges of condensed water become large enough to touch the continuous capillary water body, the capillary water front is pulled forward as far as the condensed water wedges extend. Further advances of capillary water into the dry layer may be produced by repetitions of this process. Since movement of water vapor is a very slow process unless the place of condensation is much colder than the place where evaporation occurs, capillary movement by this means may be exceedingly slow.

FORMS OF SOIL WATER

The usual classification of soil-water forms is based upon the effects produced by gravitational and capillary forces. If gravitational forces predominate, as they do if the soil is nearly saturated, water drains from the larger pore spaces, in which the capillary forces are weakest. Drainage continues until smaller pores are reached, in which the capillary forces exceed the downward gravitational pull. The water which percolates through the soil under the force of gravity is called gravitational water. The remaining water exerts no external pressure; in fact, it is under tension, and like Monday's wash on the clothesline, hangs in the soil supported by the upper capillary surfaces of the continuous water bodies. This water, called capillary water, is free to move about equally well in all directions, but it always moves in the direction of the greatest capillary tension. The term "high" or "upper" capillary range will be used to denote a condition in which capillary water is abundant, and the term "low" or "lower" capillary range, one in which the moisture is nearer the lower limit of capillary water.

When the moisture content of the soil is so low that water no longer moves under the influence of capillary forces, the remainder is usually referred to as hygroscopic water. This water is very strongly held as thin films on the soil grains, and as minute wedges and rings between the grains at their points of contact. The greater part is associated with the colloid part of the soil, which exposes an enormous surface to which a thin film of water is strongly held by physical forces of attraction. In fact the quantity of hygroscopic water a soil can hold is a rough measure of the quantity of colloid present.

As the hygroscopic moisture evaporates, a condition may finally be reached in which no more water is lost at ordinary temperatures even if the soil is placed in a very high vacuum to remove all traces of water

vapor. The remaining water, which exerts no vapor pressure, is called the water of chemical constitution, or combined water. It is held by chemical rather than physical forces, and can be driven off only by heating. At the ignition point, a bright red heat, all soil water is finally lost, the combined water permanently lost.

The four forms may be summarized as follows:

Gravitational water—percolates downward through the subsoil and drains away.

Capillary water—remains after gravitational water is removed; held by capillary attraction; moves in any direction in which capillary tension is greatest.

Upper capillary range—capillary water is abundant.

Lower capillary range—moisture content at which capillary forces cause only a slow movement of capillary water.

Hygroscopic water—remains after capillary water has been removed; mostly held as thin films on soil grains, especially colloids.

Combined water—remains after hygroscopic water evaporates; held in chemical combination, will not evaporate, and can be driven off only by heating.

Although this classification of soil water into these forms may appear to be satisfactory and logical, actually the points of division cannot be located accurately, and they may shift or overlap as conditions change. A very long time may be required for all flow of gravitational or capillary water to cease, and no abrupt change in any physical property is observed when gravitational or capillary water first becomes exhausted. Near the lower limit of capillary water most of the soil moisture moves as a vapor. As the water table falls farther below the root zone, some water previously held in the root zone by capillarity drains away as gravitational water.

Let us consider some of the things that may occur when rain falls upon a dry soil. Infiltration, which is the penetration of water into a soil under the combined forces of gravitation and capillarity, usually is rapid at first. As the water front moves down, forcing the soil air ahead, the flow decreases owing to the increasing resistance of the lengthening water channels, often made smaller by the swelling of the colloid. If rain ceases when the root zone becomes saturated, water may continue to flow downward from it into the deep subsoil or into subterranean drainage channels for perhaps less than a day or for several days. The soil then contains the maximum quantity of capillary water it can hold. This moisture condition is called the field capacity.

If the air above the soil is not already saturated, water may begin to evaporate from the soil surface soon after rain ceases to fall. As the soil surface dries, removing water from the larger pores first, capillary water surfaces retreat into smaller pores and the lifting power increases. Capillary water from the root zone below begins to move toward the surface to replace that lost by evaporation. Evaporation and plant transpiration finally reduce the moisture content to so low a value that plants growing in the soil wilt and cannot be revived except by watering. The moisture condition of the soil at this stage is known as the permanent wilting percentage or wilting coefficient.

The wilting coefficient and the field capacity are two important soil-moisture constants because crop growth takes place in this range.

Although they differ widely in various soils, they are fixed and reproducible moisture constants characteristic of each soil type. The difference between the two is the maximum available water. The moisture content of the soil at any time in excess of the wilting coefficient is the available water. It is usually expressed as percentage by weight of the dry soil, or as the number of inches of water per foot of depth of soil. Soils with a large available water capacity generally are desirable because rain or irrigation is not needed so frequently.

Again to summarize terms:

Field capacity—the amount of water left after gravitational water is removed.

Wilting coefficient—the amount of water left when evaporation and plant transpiration have reduced it to the point where plants permanently wilt.

Maximum available water—the difference between field capacity and wilting coefficient.

Available water—the amount of water in the soil at any time in excess of the wilting coefficient; expressed either as percentage by weight of dry soil, or as inches of water per foot of depth of soil.

RELATIVE VOLUMES OF SOIL MATERIAL, AIR, AND WATER

The capacity of a soil to hold water depends upon the total surface area of the soil grains, upon the shape and size of the pores, and upon the percentage of the total volume occupied by them. This percentage, called the porosity, is usually least in sandy soils and greatest in clays. The addition of organic matter increases the porosity, peat and muck soils having a much higher porosity than mineral soils. The pore space ranges from about one-third the total soil volume in sands to about two-thirds in the heaviest clays.

The volume of air space when the water content is at field capacity depends upon the character of the pore space. As a rule sandy soils have larger air volumes at field capacity than have the heavier-textured soils, because they have a greater number of large pore cavities from which gravitational forces have removed the water. If the granules of a clay soil become broken down to a single-grain structure, the soil will have few pore spaces too large to fill with capillary water; consequently the air volume will be small. If the soil develops a granular structure the air volume will be greatly increased.

Figure 3 shows graphically the relative volumes of soil material, water, and air of five soil layers, A, B, C, D, E, at field capacity and at the wilting coefficient. The material of soil A would, if collected into a single mass, occupy 7.7 inches of the 1-foot soil layer. At field capacity, this soil contains 2 inches of water, the remaining 2.3 inches being occupied by air. At the permanent wilting point, shown by the dotted line, the soil still holds 0.9 inch of water. The available water is the difference between the two moisture values, or 1.1 inches of water.

Soil A is the surface layer of a red sandy loam from Texas. Underlying it is B, a heavy red clay. Both the porosity and the water-holding capacity of the subsoil are much greater than those of the sandy layer above. The subsoil holds more water at the wilting coefficient than the surface layer does at field capacity. The moisture

difference is so great that one might expect water to rise from the subsoil into the root zone of the topsoil and become available. This will not happen because at comparable moisture values both layers have the same capillary tension and there is no unbalanced force to cause water movement.

Soil C is a Maryland loam of desirable soil-moisture characteristics. Its pore structure permits a fairly high infiltration rate, so that rain

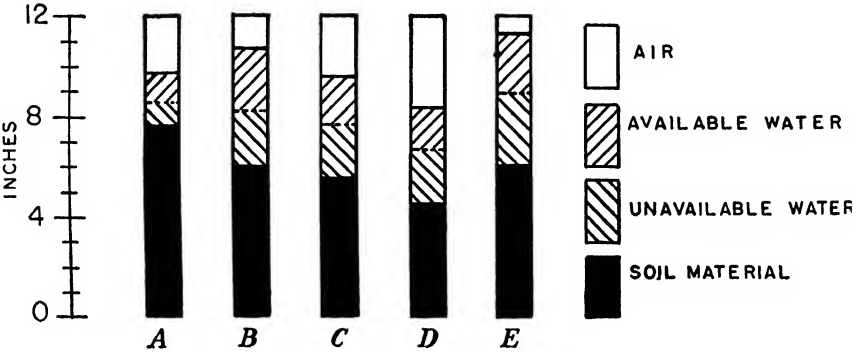


FIGURE 3.—Relative volumes of soil material, water, and air in five soils.

penetrates it quite readily. It has good drainage and aeration, yet it has a rather high storage capacity of 1.8 inches of available water per foot. From gas-absorption measurements it has been estimated that the soil grains of the underlying subsoil have a total surface area of 250 acres per cubic foot.

Soil D, a fertile black clay from Texas, has many unusual properties. Its porosity is very high, and it has much better aeration than most soils regardless of texture. This soil has a well-developed granular structure, which gives it some of the most desirable properties of both sands and clays.

Some clay loams and clays have such uniformly fine pore assemblages that they are nearly saturated at field capacity, with the result that the supply of oxygen for plant roots is insufficient. Crops in these soils do not suffer from too much water but from too little oxygen. Soil E, the clay subsoil of a Missouri silt loam, has only 0.6 inch of air space at field capacity, and this is no doubt so disconnected that very little diffusion of air takes place. This soil would be slow to take up water, slow to drain, and consequently would lose much water by surface run-off.

THE STORAGE AND CONSERVATION OF AVAILABLE WATER

The supply of soil solution to plant roots is governed by capillary flow, which is greatest when capillary water is abundant. Thin moisture films move very slowly even when the capillary tensions are high. In order to understand how soil-water storage depends upon capillary conductivity, consider what happens after a bare soil has just been wet to saturation to the full depth of the root zone, with dry soil beneath. Water immediately begins to flow downward,

rapidly at first, but in a few days, after the supply of gravitational water is exhausted, the water space front may not advance into the dry layer faster than 1 inch per week.

A similar condition exists at the soil surface. As evaporation proceeds, rapidly at first, capillary water rises to replace part of that evaporated. After a few inches of surface soil becomes dry, capillary connections to the surface become broken, and water can leave the soil only by the slow process of evaporation from the upper capillary fringe and diffusion through the dry layer above. The net result is a root zone stocked with water nearly to field capacity and protected from loss by dry layers above and below. This water may be held for weeks or even months with only slow losses. In dry-farming regions this principle of the slow movement of capillary water into dry soil forms the basis for the practice of fallowing. Rain which enters the uncropped soil, kept free from weeds by light cultivation, is stored for use of a crop the following year.

It sometimes happens that a subsoil containing an abundance of available water may become separated from the moist root zone above by a dry layer. The capillary conduction and vapor diffusion of water upward through the dry layer is so slow that only a very small portion of the crop's water requirements may be obtained from that source. Since plant roots cannot penetrate the dry zone, the crop may experience a drought with an abundant supply of water less than 1 foot away. If the intervening dry layer is moistened by a rain or irrigation, the stored subsoil water becomes available.

A drought may also occur when a water table lies only a few feet below the deepest plant roots. The capillary tensions in a sandy layer may not be great enough to lift water to the root zone. If the soil is a clay, tensions great enough to lift water 100 feet or more may easily be obtained. However, the resistance to the flow of capillary water in the fine pore spaces may be so great that weeks or even months are required for a capillary rise of only 4 or 5 feet. Even in soils of the most favorable pore structure it is probably seldom that crops obtain a significant part of their water requirements from the water table if it lies more than 6 to 8 feet below the bottom of the root zone. If crops are to obtain much water from an underground supply, they must send their roots down to it.

Some farmers in subhumid regions give a shallow cultivation to row crops as soon as possible after every rain in order to maintain a soil or dust mulch, to serve as a barrier to both the rise of capillary water to the soil surface and the downward conduction of heat that would induce a high evaporation rate. The results of soil-mulch experiments do not all agree, but the weight of evidence is that when there is no water table near the surface, the soil mulch does not conserve soil moisture any better than the uncultivated soil surface, which dries out and becomes self-mulched. In most instances the greater part of the water loss has already taken place before the soil is dry enough to be cultivated.

After a soil mulch is established, a light rain or irrigation may do more harm than good if it wets down just far enough to make contact once more with the upper fringe of the capillary water curtain. Evaporation is now able to remove water formerly regarded as safely

stored. This is a principle that everyone who gives his garden a light sprinkling at irregular intervals should understand. Another is that water penetrates only so far as it wets the soil thoroughly. Consequently, the addition of a small quantity of water, instead of distributing itself evenly throughout the root zone, wets only a thin surface layer. It may evaporate within a day. The practice of giving the lawn a light daily sprinkle results only in the development of feeding roots near the surface. If watering should be discontinued for a few days the grass might suffer a real drought.

Although a soil mulch may not conserve soil moisture directly, it still may be beneficial through decreasing the flow of heat into the soil and killing weeds which remove water from the soil by transpiration. Perhaps the greatest benefit lies in putting the soil surface into a loose open condition favorable to the reception of water during the next rain. Soil moisture can be conserved by covering the soil surface soon after a rain with straw, paper, stones, dry sand, or any other substance that does not make capillary contact with the wet soil surface.

SOIL-MOISTURE LOSSES

Soil-water losses are usually classified as run-off, evaporation, transpiration, and percolation. All these losses depend upon the capacity of soils to transmit water. Evaporation and transpiration probably account for about half the total loss in humid regions, and for more than that in less humid areas. Both remove water only from the root zone.

Percolation is the passage of water down through a saturated soil layer and therefore follows the laws of flow of gravitational water. If one of two soils of equal porosity has 100 times as many capillary pores per acre as the second but each pore is only one one-hundredth as large, then the soil with the fewer but larger pores will have a 100-times greater percolation rate. Sands may have percolation rates many thousand times as fast as those of clays. Percolation, like excessive run-off, impoverishes the soil. Percolation removes soluble products of the soil, whereas excessive run-off removes the soil itself. Little or nothing can be done to prevent percolation. It is usually desirable to remove percolating water through drainage channels as soon as possible and to hold run-off until the soil can receive it if possible. In about half the land area of the United States the rainfall is so low that there is no percolation into underground drainage channels; a very much larger area is subject to surface run-off.

Transpiration is the excretion of water vapor by the leaves of plants, and represents soil water that has been used for crop production. In this use of soil water the plant cooperates, the roots moving to the water as well as water to the roots. For soils in good tilth root hairs may be found in nearly every thimbleful of soil within the main root zone. Most of the available water supply in the soil has to move only a fraction of an inch to reach an absorbing root. When a plant root makes contact with the water in the soil, the capillary tension is increased at that point, and a flow of water toward the root hair begins. As the available water supply is used, eventually the maximum suction force of the plant, which does not greatly exceed 250 pounds per square inch, is not great enough to obtain an adequate flow of water, and the plant wilts.

There is a widely held belief that plants grow best when the soil is at a rather high moisture content, near the upper capillary limit, called the optimum moisture content. However, experiments indicate that crops grow and yield about equally well at all moisture contents within the capillary range from slightly above the wilting coefficient up to field capacity for all soils except a few heavy clays with a very low capillary conductivity.

SOIL PLASTICITY

Farmers who have had experience with many kinds of soils know that sandy soils can be plowed or cultivated about equally well wet or dry, that many loams have a rather wide moisture range in which they may be worked satisfactorily, but that most fine clays must be tilled only when the moisture content is just right. This difference in soil behavior is due to plasticity, a flow property of soils that makes it possible to mold wet soils into forms that are firmly retained upon drying—a property familiar to all who have made mud pies.

Plasticity is a property of only the clay or colloid fraction of the soil. Not even the finest silt-sized soil particles are plastic, although some finely ground platy minerals such as mica are. When the water envelopes surrounding the clay particles are thick enough, the soil swells, and the particles may be made to move over each other without crumbling. The lower plastic limit is the lowest moisture content at which the soil can be molded with the fingers into a single-grain mass. At all higher moisture contents the soil is plastic.

If one molds a bit of plastic soil in the hands while water is being added, a moisture content is reached at which the soil begins to stick to the fingers. The stickiness becomes greater at higher moisture contents and ceases at lower ones. The lowest moisture content at which stickiness first appears is called the sticky point. This is also approximately the moisture condition of a soil at which a plow or tillage instrument just fails to scour. Stickiness is a property of plastic soils only.

Plastic and nonplastic soils have different types of shrinkage. When a wet nonplastic soil dries, it shrinks by exactly the volume of water lost until shrinkage ceases entirely. Wet plastic soils also lose water in this manner at first. Later the shrinkage gradually becomes less for equal moisture losses, until shrinkage finally ceases. This second type of shrinkage, called residual shrinkage, is an important property of plastic soils.

In order to manage a plastic soil best it is necessary to maintain its granular structure. It is not known why some soil granules are so hard when dry, but it is well known that the forces holding them together weaken greatly when the soil is wetted. When saturated with water, the granules may fall apart easily if disturbed by such things as the trampling of livestock or even the pounding of heavy rain. If a plastic soil is well stirred or puddled when wet, it dries into a hard, compact mass, with a single-grain structure, that cannot be tilled satisfactorily.

From these properties of plastic soils it may be readily understood why it is important that they should be cultivated when the moisture content is just right. If tilled when too wet, granulation is destroyed,

and if they are plowed when dry, large clods are formed which do not make a good seedbed. Such soils should be tilled when the moisture content is in the residual shrinkage range, because in this range contracting capillary water surfaces exert considerable tensions, which, as shown in figure 2, pull groups of soil grains closer together. Soil granulation, if destroyed, may be restored by repeated wetting and drying through the residual-shrinkage range. Newly formed aggregates are weakly bound together, but they grow in size, strength, and number with each moisture cycle until finally good tilth is restored. Those who till plastic soils should strive never to destroy their original granular structure because it is likely to be better developed and more permanent than any that can be brought about through tillage practices.

In some soils granulation is easily destroyed and is restored with difficulty. The addition of lime, which causes flocculation of the clay, may be helpful. Heavy-textured soils with a high calcium content usually have the best-developed and most permanent granulation. Since sand and silt are not plastic, it might be expected that adding them to plastic clays would improve the tilth of the latter. This is true, but the quantity required would be so great that the treatment would not be practicable except in small gardens. Organic matter is much more helpful. It raises the sticky point, reduces plasticity, increases granulation, promotes better drainage, and consequently increases both tilth and fertility.

THE EFFECT OF SOIL CHEMICAL PROPERTIES UPON SOIL WATER

Many of the statements made in the preceding discussion of clay soils do not apply to all clays. For example, some tropical soils behave much like sandy soils although their mechanical analyses show them to be heavy clays. They are not sticky or plastic and do not exhibit the property of residual shrinkage upon drying. In fact they have little shrinkage of any kind. They have such a firm granulation that they can be plowed immediately after a rain without injury to tilth. These soils, known as Laterites, are described in a later section. It is desired here merely to point out that soil-moisture relations are affected not only by the quantity of clay but also by its chemical character. Few if any soils of the United States possess the unusual physical properties of the tropical Laterites, but many of the red soils of the Southern States exhibit these characteristics to a lesser degree. The moisture properties of ordinary clay soils, such as swelling, shrinkage, plasticity, and percolation rate, may be greatly altered by driving off at a high temperature some of the combined water.

SOIL MOISTURE CONSTANTS

A few of the many terms used to designate soil-moisture relations are shown on the moisture scale, figure 4. Many of these terms have been used previously and will not be defined here. Their arrangement on the scale is only approximate. The relative position and order will not be the same for all soils because each soil has its own moisture scale.

This scale, with the moisture content increasing upward, has no top. Above A are the soil suspensions in which the soil particles, usually only fine ones, move around in an excess of water. The highest reasonably permanent soil volume is the settling volume, which is the space occupied by a unit weight of soil after settling from a suspension. From A to B is the region of gravitational water.

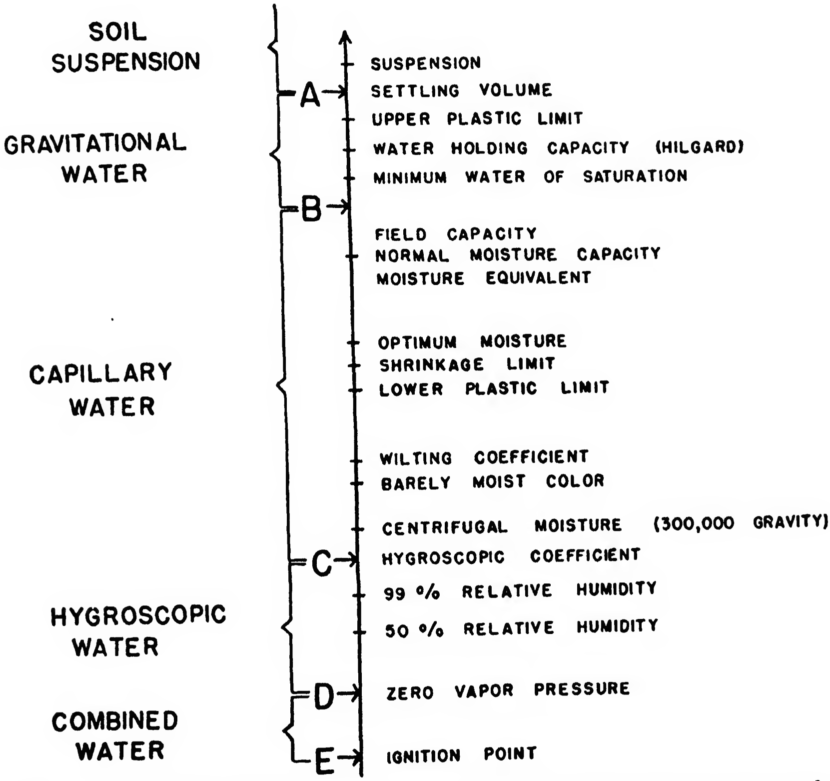


FIGURE 4.—A soil-moisture scale showing the approximate location of commonly used soil-moisture terms.

Near the top of this range is found the upper plastic limit, the moisture content below which soil pastes no longer behave like liquids. The maximum water-holding capacity is the moisture content of a 1-inch layer of loose soil after gravitational water has drained from the largest pores. The minimum water of saturation is the lowest moisture content at which a soil may be saturated with water when the soil grains are worked into the position of closest packing.

The moisture scale between B and C is the very important capillary range. The capillary tensions vary from zero at B to several hundred pounds per square inch at C. The normal moisture capacity is a laboratory test of field capacity. It is the maximum quantity of water a soil can hold when in contact with a dry layer. The moisture equivalent is the moisture content of a soil sample three-eighths

inch deep when subjected to the gravitational pull of the earth, magnified 1,000 times by means of a centrifuge. This is one of the most useful of laboratory tests. The moisture equivalent is approximately equal to the field capacity for most soils except the coarsest and some of the finest. For many soils the wilting coefficient is approximately 0.54 times the moisture equivalent, and the hygroscopic coefficient is 0.37 times the moisture equivalent.

It has been found that the greater the moisture range between the upper and lower plastic limit the more plastic the soil will be. The sticky point always lies in this range. As plasticity decreases the lower plastic limit rises to the sticky point, and then both disappear. When this occurs, the soil is not plastic. The shrinkage limit is the moisture content of a molded cake of drying soil at which shrinkage ceases.

The point at which soils show a barely perceptible difference in color from the air-dry condition is indicated here merely for reference. It lies somewhere near the lower limit of capillary moisture, not far from the point on the moisture scale where a small decrease in water greatly hardens a plastic-soil crumb.

The range from C to D on the moisture scale is the hygroscopic range in which water can move in the soil only by evaporating at one point and condensing at another. The hygroscopic coefficient which marks the upper limit of this range is usually determined by exposing a thin soil layer to an atmosphere saturated with water vapor for a period of about a day. This test is not very satisfactory, because if the soil sample is exposed to a water-saturated atmosphere long enough it will pick up a considerable quantity of capillary water. A better test is to expose the soil sample for 5 days to an atmosphere only 99 percent saturated with water vapor. Since this sample will continue to pick up small quantities of water for weeks, the moisture content at the end of 5 days may be slightly below the hypothetical and elusive hygroscopic coefficient.

As the relative humidity of the air decreases the soil loses moisture. The moisture content of air-dry soil usually lies on the moisture scale somewhere between the 40- and 85-percent relative humidity points, the position depending upon the climate. The lower limit of the hygroscopic range (D) occurs when the soil is so dry that, at ordinary temperatures, there is no further tendency for water to escape. This point of zero vapor pressure is a very useful reference point in soil-moisture studies and in both physical and chemical work is taken as zero on the moisture scale. It may be determined by exposing a soil sample to a high vacuum or to an atmosphere kept dry with concentrated sulphuric acid, but it is usually determined by drying a sample in an oven at a temperature not more than 10° above the boiling point of water.

THE SOIL may be likened to a vast chemical laboratory in which complicated changes are constantly going on. It is difficult to describe what occurs in this great laboratory briefly and in nontechnical language. In the first part of this article the general reader becomes acquainted with some of the elementary facts about soil colloids, base exchange, soil acidity, and the soil solution. The last part of the article deals with these subjects in more detail for readers who have some acquaintance with elementary chemistry.

General Chemistry of the Soil

By HORACE G. BYERS, M. S. ANDERSON and RICHARD BRADFIELD [1]

SOME ELEMENTS OF SOIL CHEMISTRY

THE chemistry of the soil involves many and very different chemical compounds. The most important group is composed of the compounds of the element silicon, which make up more than 75 percent of the various soil layers. The silicon compounds of soil are derived from the decomposition of every kind of silicate rock on the face of the earth. The products of these rocks have been modified in part by the action of plants and animals of all kinds growing on the soils and contributing their remains to the already complex soil material. The remains of living organisms usually contribute from 1 to 10 percent of the weight of the upper few inches of surface soil. The silicon compounds and the carbon compounds, associated with life processes, are the most numerous and the most complex of the compounds found in nature.

In each class certain relatively simple compounds may be separated and identified. Crystalline silicon oxide, known as quartz, predominates among the larger sand grains. Simple carbonates are among the few carbon compounds of soil that can be separated and identified. The great majority of the compounds of both groups that predominate in soil are very complex and in many cases not well understood. This is one reason why any simple discussion of soil chemistry is confronted with the necessity of important omissions of facts or with a compromise with accuracy of statement.

The older textbooks on agricultural chemistry list 10 elements as essential to plant growth. Of the group, carbon, hydrogen, and oxygen come from the air and water, while phosphorus, sulphur,

[1] The section Some Elements of Soil Chemistry is by M. S. Anderson, Senior Chemist, Soil Chemistry and Physics Research Division, Bureau of Chemistry and Soils. The section More Technical Soil Chemistry is by Horace G. Byers, Principal Chemist, in the same Division; M. S. Anderson and Richard Bradfield, Professor of Soils, Cornell University.

nitrogen, potassium, calcium, iron, and magnesium are obtained by the plant from the soil. Modern science is recognizing others, including manganese, copper, zinc, and boron, as essential to balanced growth. Most of the various mineral elements occur in the rocks from which soils are formed. By natural processes, particularly by the action of water, and over long periods of time, the larger rock grains are reduced to a very fine state of subdivision and are then able to play a part in furnishing nutrients to plants.

Soil Colloids

The chemistry of the fine clay portion, or what is technically known as the colloid fraction of the soil, has in late years taken a prominent place in soil research. A few years ago the term "colloid" was essentially reserved for use in highly technical literature, but the significance of colloids in industry, medicine, and other subjects has led to more common usage of this term. It always refers to very small particles, usually too small to be seen with an ordinary microscope. Such materials often form a jelly when proper quantities of water are present. Inorganic soil colloids are the residues of rock particles that have been washed for ages by water and through this washing have lost much of their lime, potash, and other mineral constituents. The mineral matter retained by the soil colloid contains plant nutrients that slowly become available for the use of plants growing in the soil. It is the storehouse for the years, near at hand. Over a long period the larger rock grains are reduced to colloidal sizes and thus play a part in furnishing nutrients to plants.

The character of the colloidal material of a soil varies widely with general group classification of the soils. Finer distinctions between somewhat similar soil groups are often difficult to make. In general, it may be said that the ratio of the quantity of silica present to that of alumina and iron oxide is the most important chemical characteristic of the soil colloid upon which to base judgment of the fundamental character of a soil, since other important differences usually vary with this factor, the constituents of which involve 50 to 90 percent of the total mineral matter of most soil colloids. The fundamental soil character indicated by the chemical character of the colloids may frequently be used to identify the general locality in which a soil was developed. For instance, a few years ago, after severe nation-wide dust storms, scientists collected a small sample of dust from snow in Vermont. Chemical analysis showed that this material undoubtedly came from a region west of the ninety-seventh meridian, which passes through eastern Nebraska and Kansas. Broad differences of this kind can be determined by soil chemistry. Smaller differences necessitate less certain interpretations from chemical data.

Since plant nutrition and agricultural practice are largely determined by the character of the soil colloids, it follows that good tillage and fertilizer practices developed by farmers are based upon knowledge of colloid behavior, even though that knowledge may have been gained through experience only and in total ignorance of either the term "colloid" or of the existence of such material.

Soil colloids affect the properties of soils in so many fundamental ways that it is difficult to refer to any soil function not related in some

way to this important fraction of the soil material. In dry-land regions the mineral colloid fractions have undergone only moderate chemical change from the action of water. They retain a large part of their original bases, such as sodium, calcium, and potassium. Their silica content remains high. The typical colloidal properties are very pronounced; that is, the colloids swell when water is added and disperse when agitated with greater quantities of water. When they are dispersed and the water content is reduced, they form jelly masses which, when further dried, become almost impervious to water. This last property of colloids makes irrigation and drainage very difficult, if not impossible, in certain localities. It is sometimes necessary then to change the colloidal properties by some means before these operations can be successfully undertaken.

Under prairie agricultural conditions the soil colloids have been a little more weathered and the accumulation of much organic matter in the surface soil has enhanced their fertility. In the northern forested regions, active changes in the soil colloids are under way. Organic and mineral matter at the surface is dissolved, dispersed, and transported downward, where it is concentrated in a layer containing much iron and organic matter. Sometimes this material acts as a cementing agent, giving rise to a layer of hardpan. The chemical composition of the colloids of such soils, described elsewhere as Podzols, is markedly different from that of other soil groups. In the Red and Yellow, or lateritic, soils, the colloids have undergone still different changes. Weathering has proceeded to a marked degree, leaving an excess of iron oxide and alumina, with a greatly reduced silica content. These soils are usually acid and have lost through base exchange a very large part of their original base constituents.

Base Exchange

Base exchange is a property of soils that has very important practical applications. When a simple salt, such as the ordinary fertilizer constituent muriate of potash (potassium chloride), is added to a soil, it does much more than simply increase the concentration of potash in the soil solution. Instead, some potassium changes places in the colloidal particle with calcium, sodium, and other mineral base elements, and these in turn enter into the soil solution. The result is that only a part of the potassium which was added in solution remains water-soluble. The increased concentrations of other constituents set free may enrich the soil solution in other ways and make it better balanced for plant growth. This process, by which one base goes from solution into insoluble form and another comes out into the solution to take its place, is known as base exchange. It is a great soil-conserving factor, since it retards the excessive leaching out of such valuable constituents as potash and ammonia. By base exchange it is possible to improve soils whose physical condition has become bad from excess of sodium. Hydrogen or calcium may be substituted for a part of the sodium. Sometimes exchange is accomplished by the addition of sulphuric acid in small-scale operations, or sometimes by the addition of calcium salts, such as calcium chloride, in irrigation districts. Base exchange takes place slowly from the action of water on soil colloids under natural conditions. The traces of carbonic acid in the water

replace lime and other constituents to form a colloid of increasing hydrogen content; that is, to form a more acid soil. Thus, when soil leaching has been excessive over long periods, soil acidity becomes an agricultural problem, both from the standpoint of intensity of the acidity and also from the depletion of various soil bases that has taken place through the base-exchange process.

Soil Acidity

Soil acidity is described by various terms, such as hydrogen-ion concentration, reaction, pH values, or exchange acidity. Each of these terms refers to a measurement of acidity in some form. In regions of low rainfall where leaching has not been excessive, acid soils are infrequent. In such regions the opposite of this, alkaline condition, frequently develops. The so-called black alkali (alkaline carbonates) regions of the West result from the accumulation of bases in a soluble form. Throughout the regions of moderate rainfall some moderately acid soils are found, and others are neutral or alkaline, depending to a considerable extent on the character of the parent material. In regions of high rainfall soils are usually acid to varying degrees unless their parent material is highly calcareous, and even then strongly acid soils are frequently found with underlying calcareous material only 3 or 4 feet, or even only a few inches, from the surface. A nearly neutral or slightly alkaline soil is frequently considered the best for agricultural purposes; however, no broad statement of this kind is justified.

The degree of acidity (pH) controls in a very significant way the adaptation of various crops and native vegetation to soils. For instance, cranberries can be successfully grown only in soils moderately to strongly acid. Alfalfa and various other legumes are ordinarily successfully grown only in slightly alkaline or in not more than weakly acid soils. Some of the great agricultural crops of this country, such as corn, are apparently indifferent to soil-acidity conditions within a fairly broad range. The application of lime in some form, either limestone, dolomitic limestone, or burnt lime, constitutes the ordinary procedure for correcting soil acidity. In order to ascertain what the lime requirement of a soil is, many factors must be taken into consideration, particularly the kind of crop to be grown. When lime is added, a typical base-exchange reaction takes place; i. e., the hydrogen of the complex soil colloid is exchanged for the calcium of lime. Acid soils are found within a great many soil series but predominantly in regions of high rainfall.

Soil Solution

As previously mentioned, soil solutions arise primarily from the action of water upon the colloidal soil material. All of the minerals taken up from soil by plants probably enter the plants through the soil solution. The water around the grains of fertile soils never contains a large amount of mineral matter in solution at one time, but the character of the colloids determines whether or not mineral matter will continue to dissolve rapidly enough to support continued good growth of plants. Part of the soil solution is utilized by the plants, another part is usually drained away, while in certain cases still

another portion seeps down to lower levels and collects in depressions until the concentration of the soil solution increases. Under certain circumstances it becomes too high for plant growth. Such soils are said to contain alkali, though they are not always really alkaline in character. They are, however, salty and often contain considerable quantities of ordinary table salt, as well as other salts such as calcium chloride and sodium sulphate.

Nature has provided that most plants may thrive in a fairly wide range of concentration of soil solution. Water extracts of some soils that produce good crops contain no large quantity of dissolved material, perhaps 15 to 100 parts per million. On the other hand, these same crops have been grown experimentally in the so-called tank agriculture, with many times this concentration of salts in solution.

Soil Organic Matter

The chemical nature of soil organic matter is so complex that only very general statements regarding it can be made here. Soil organic matter contains many compounds of varying properties. Some of it is intimately associated with the silicate minerals as a part of the soil colloids. It acts as a weak acid and is capable of holding large quantities of bases as a part of its composition. It also has basic properties, which enable it to combine with acid material such as phosphoric acid. Most of the compounds contain nitrogen and serve as food for the growth of bacteria, fungi, and various other forms of life. The processes of life, death, and decay leave byproducts that aid plant growth. The maintenance of an adequate supply of active organic matter is one of the important problems of permanent agriculture.

Soil Chemistry Research

The problems that soil chemists are called upon to solve are many and varied. Frequently they are concerned with only one phase of a broader agricultural problem where such sciences as physics, botany, and other branches of biology have a part.

There is space for only one example of a problem solved by soil chemistry. A few years ago it appeared that the repeated heavy applications of calcium arsenate used for control of the boll weevil of cotton had a detrimental effect on cotton yields in certain areas. It was evident also that the detrimental effects were much more pronounced on some soils than on others. Chemical investigations showed that this variation in toxicity of added arsenic was related to the free iron oxide content of the soils. Arsenic in the condition of that added forms a very insoluble compound with the iron oxide. Thus the red soils with relatively high iron contents showed but little detrimental effect, but caution was needed in applying arsenic to those of light colors.

Numerous problems are concerned with the causes of infertility of various soils, either in local spots or in large areas. Such problems are attacked in different ways depending upon the symptoms. In one area abnormal quantities of nickel and chromium were found, which probably were the detrimental constituents. In many areas the chemical information gained from acidity tests forms a basis for improved farm practice.

Much of the work of a soil chemist has no popular appeal. It involves the accumulation of chemical data related to soil classification and to other broad lines of soil work. Such data, which add to our knowledge of soils, aid in a more ready solution of practical problems as they arise.

MORE TECHNICAL SOIL CHEMISTRY

Soil consists of the decayed residues of minerals and of organisms that have existed upon it or in it. The organic remains are derived from the decay of both plants and animals and of animal excreta. As a rule the decayed products are mixed with fragments of the parent materials, which are still subject to further change by physical and chemical weathering, i. e., to further decay. As a rule, also, the soil contains living organisms such as plant roots, bacteria, insects, and large animal organisms; but these, however important they may be to the behavior of plant growth in the soil, are not usually considered as an essential portion of the soil itself.

The substances composing the soil exist for the most part in incomplete equilibrium with the environmental conditions and with each other. That is to say, the materials of the soil, while subject to change, actually change slowly in short intervals of time; or if they change rapidly, replacement of the changed material is likely to occur. In illustration of this, attention may be called to the very slow change of mineral fragments to fine soil material (clay) and to the rapid seasonal decay of vegetation and its frequent replacement. In general, the soil of a given area is likely to remain of essentially constant character from year to year unless subjected to artificial alteration at the hands of man or to some violent change as a result of disturbances of nature, such as storms.

The soil materials present in a given soil, so far as their chemical composition is concerned, depend in part upon the rocks from which they were produced, in part upon the climate (temperature and rainfall conditions), and in part upon the kinds of vegetation developed upon them.

This article is concerned with the character of the inorganic (mineral) components of the soil and its bearing upon certain aspects of soil behavior and use.

Mineral Composition of the Soil

Almost any of the entire list of chemical elements may be expected to exist in the soil. Indeed, a very large number of them have been shown to be present in many soils.[2]

However, the greater part of the inorganic portion of the soil consists of a relatively small number of elements. That this should be true is evident from consideration of the composition of the earth's crust from which they are derived. The sources of the soil are usually igneous rock, shales, or sandstones (including residues from carbonates). The approximate relative quantities of the mineral components of these sources, as given by Clarke (*65*) [3] are shown in table 1.

Of the minerals listed in table 1, quartz is essentially silica (SiO_2), an oxide of the element silicon (Si), of which sand is the form most commonly known. The feldspars, clay, hornblende, pyroxene, and mica are minerals called silicates which consist chiefly of the elements silicon (Si), aluminum (Al), and oxygen (O), in combination with each other along with considerable quantities of the elements iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), and usually with traces of other elements. It must be clearly understood that none of these elements exists as such in the minerals; they are always in chemical compounds. Limonite is one of the hydroxides of iron ($Fe(OH)_3$). The carbonates are chiefly salts of calcium and magnesium, e. g., limestone ($CaCO_3$). Of the minerals listed as "Other minerals" the greater part also consists of compounds of silicon, aluminum, and iron.

It is not surprising, therefore, that soils, as decay products of these minerals, consist largely of the elements named above and that the most abundant of these are oxygen, silicon, aluminum, and iron.

[2] The significance of minor elements is treated elsewhere in this Yearbook, as are also various other topics with which soil chemistry is intimately related. Without further citation the reader is referred to other articles when additional details or meanings of terms are desired. Some of them are Water Relations of Soils, Soil Organic Matter and Soil Humus, The Physical Nature of Soil, Formation of Soil, and Soil Classification.

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

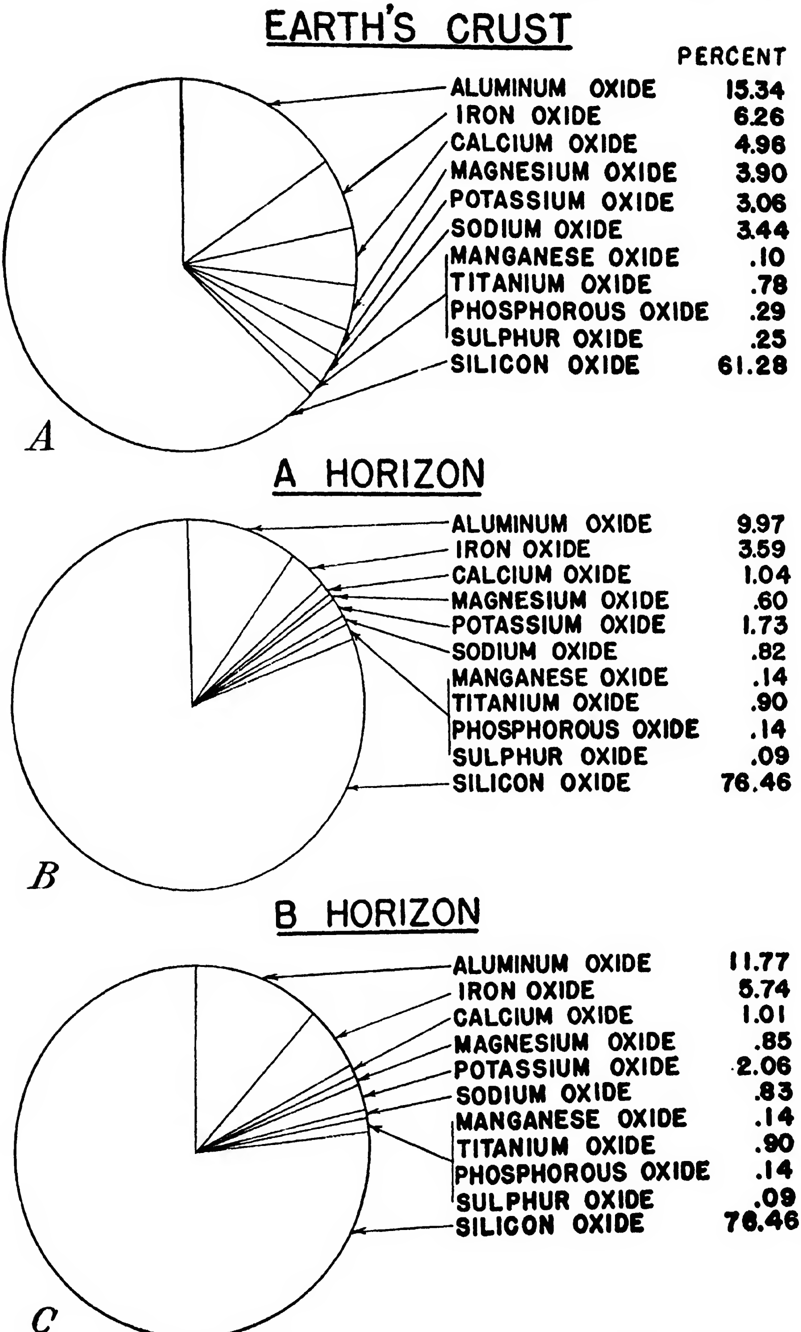


FIGURE 1.—The approximate composition of the earth's crust (*A*), and *B* and *C*, mean composition of the A and B horizons, respectively, of 18 representative soils.

Table 1.—*Approximate mean mineral composition of igneous rocks, shales, and sandstones*

Mineral	Igneous rocks	Shales	Sand-stones	Mineral	Igneous rocks	Shales	Sand-stones
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
Quartz	12.0	22.3	66.8	Mica	3.8	-------	-------
Feldspars	59.5	30.0	11.5	Limonite	-------	5.6	1.8
Clay	-------	25.0	6.6	Carbonates	-------	5.7	11.1
Hornblende and pyroxene	16.8	-------	-------	Other minerals	7.9	11.4	2.2

In the chemical analyses of both minerals and of soils it is usual to express the results obtained as the percentage quantities of the oxides of the elements determined. When the sample has been freed of organic matter and water, the sum of these percentages approximates 100 very closely. It must not be supposed, however, that the minerals or soils contain the free oxides of the elements except in certain instances. This method of stating the composition permits a mode of expression of the relation between soils and their parent minerals shown in figure 1.

Figure 1, *A* expresses the approximate mean composition of the earth's crust, as estimated by Clarke (*65*). Figure 1, *B* and *C*, expresses in corresponding terms the mean composition of 18 ignited soils. The soils are all agriculturally important ones. Figure 1, *B* shows the mean composition of the A horizon (surface soil) and *C* the mean composition of the B horizon (see The Physical Nature of Soil, p. 889). Were the mean analytical values of all soils obtained the result would probably not differ widely from the figures given. From these figures it may be seen that both soils and minerals have the same general composition, when expressed as oxides. The transformation from minerals to soils is accompanied by a marked decrease in the percentages of calcium, magnesium, potassium, and sodium oxides, ordinarily termed the bases, and relatively smaller losses of aluminum and iron oxides, while the average silica content is relatively higher. It may be particularly mentioned that while all soils contain small quantities of numerous other elements, including titanium, phosphorus, sulphur, and many others, the distribution of these elements in the minerals is not so general.

The process of transformation of parent minerals into soil is called weathering and involves the breaking down of the minerals and rocks into smaller fragments, their segregation in various ways (physical weathering), and also chemical changes which produce different substances (chemical weathering). Through these processes the soil becomes a complex mixture of particles of various sizes. The distribution of particles of different sizes varies widely in different soils, and the relation is determined by mechanical analysis. The relative quantities of the particles determine what is known as soil texture.

The chemical composition of the particles of various sizes is also very different in different soils and even in any given soil. In general the larger particles are similar to, or identical with, the minerals from which the soil is derived, since for the most part they are mineral fragments. On the other hand, the very small particles are likely to be very different in chemical composition and chemical behavior from the parent minerals. This statement applies chiefly to particles which when suspended in water are of a maximum diameter of 0.002 mm (0.00008 inch). (To avoid the use of such small decimal values, 0.001 mm is called 1 micron.)

For the most part the very fine particles exist in the soil as complex compounds called alumino or iron silicates, which are capable of holding in chemical combination certain basic and acidic radicals (to be discussed later) and water. The chemical changes from rocks and minerals to clay are very involved and cannot be given in detail; in fact, the steps are not fully known. An example of the kinds of changes believed to take place follows.

The clay of most soils is derived chiefly from feldspars, a frequently occurring kind of which is orthoclase. It has the chemical composition represented by the formula $KAlSi_3O_8$. This mineral slowly reacts with water and produces a series of compounds. They may be represented by the following equations, which present a sort of picture of what may occur as a result of mineral decay:

(1) $KAlSi_3O_8 + H_2O \rightarrow KOH + HAlSi_3O_8$

(2) $HAlSi_3O_8 + H_2O \rightarrow H_3AlSi_3O_9$

(3) $H_3AlSi_3O_9 + H_2O \rightarrow H_3AlSi_2O_7 + H_2SiO_3$

(4) $H_3AlSi_2O_7 + H_2O \rightarrow H_3AlSiO_5 + H_2SiO_3$

(5) $H_2SiO_3 \rightarrow H_2O + SiO_2$

Of the above compounds the potassium hydroxide (KOH) leaches out of the soil through drainage, as does also a part of the silicic acid (H_2SiO_3). A portion of the potassium hydroxide reacts with the finely divided alumino silicates and a portion of the silicic acid loses water and forms secondary silica which remains in the soil. If the parent feldspar, or other mineral, contains iron (Fe) it may behave just as does aluminum and produce ferrosilicate. Often, however, especially when soils are developed in moist climates, the chemical changes of similar type go farther and leave the iron in the form of ferric hydroxide ($Fe(OH)_3$) of ferric oxide (Fe_2O_3). Also to some extent the further chemical decay of the alumino-silicates may leave in the soil some aluminum hydroxide ($Al(OH)_3$) or alumina (Al_2O_3). In case the minerals contain other basic elements, such as calcium, magnesium, or sodium, their fate is similar to that of potassium. The portion of the bases dissolved in water is in part reabsorbed by the soils through which they pass, and as animal and plant remains decay in the soil their inorganic residues become part of the soil. Frequently their basic constituents become combined with the clay.

While the picture presented above is not sharply defined and the usual quantitative significance is not assigned to the equations, yet it is apparently true that changes of the type indicated actually do occur. The relative amounts of the compounds present in different soils vary widely, depending upon parent material, climate, age, and other conditions.

In addition to compounds of the kind mentioned above, the clay of a soil may contain a considerable number of other components varying in quantity and character. Among these the most abundant and the most widely distributed is the oxide of titanium (TiO_2), which ranges in quantity from a fraction of 1 percent to several percent. Essential components also are compounds of sulphur and nitrogen, which are for the most part, but not wholly, associated with the soil organic matter. Present also, as indicated in figure 1, are compounds of phosphorus.

Soil Colloids and Their Composition

The greater portion of the clay found in soils, as well as of the organic matter, can by suitable treatment be suspended in water and made to remain so suspended for considerable periods of time. This suspended material possesses many of the properties of glue, albumins (such as egg white), and other plastic materials, which are collectively known as colloids, from the Greek word kolla, glue. It is therefore known as soil colloid. By arbitrary definition the term is applied, at least in the Department of Agriculture, to that portion of the soil consisting of particles 1μ or smaller in diameter. However, it is probable that not all particles of these dimensions possess marked colloidal properties. It is rather difficult to comprehend quantities so small as are the colloidal particles of the soil. Recent work indicates that the average diameter of the soil colloid particles is about 0.05μ and that it would require 500,000 particles to make a continuous row 1 inch in length. The average specific gravity of these particles is 2.7; assuming for purposes of calculation[4] that they are spherical, which they appear to be when suspended in water, a pound of them opened up and spread out as a flat surface would cover an area of approximately 5 acres. As compared with the colloids, the number and surface of the larger particles are negligible.

It has been clearly shown that the greater part of the important functions of the soil such as moisture relations, fertility, response to cultural treatment, etc., resides in the soil colloid and that the chemistry of the soil in its relation to plants

[4] Certain observations indicate a possible spherical form for the colloidal soil particles when associated with much water, as is the case in a suspension. However, stronger evidence points to the preponderance of either plate or rod shapes. Some of the evidence is: (1) If dilute soil colloid suspensions are stirred or caused to rotate in a flask, definite streaming effects are observed; (2) there is a big difference in ultramicroscopic counts made in random motion compared to similar counts made in an electric or electromagnetic field; (3) scintillating effects are observed in the ultramicroscope; (4) results of X-ray analysis also point to a platy structure in some of the clay minerals.

is essentially the chemistry of the soil colloid. The enormous surface of the soil colloid only partly explains these facts. It is also evident that different soils have colloids of differing composition.

From extensive studies it seems clear that the alumino-silicic acids, and related compounds, which are assumed to exist in the soil colloid, belong to the type of compounds known as amphoteric. This means that they are capable of chemical reaction with bases such as the hydroxides or oxides of calcium, magnesium, potassium, and sodium to form salts somewhat less stable than the acids themselves. At the same time they are able to combine with acidic constituents such as the acid radicals of phosphoric acid, arsenic acid, sulphuric acid, etc. These radicals, like the basic elements, are not firmly held in the presence of water and tend to split off as soluble components of the soil solution.

The soil colloid may, then, when dispersed in water, be regarded without serious error as consisting of minute particles made up of one or more, usually several, of the acids mentioned (p. 919), in which a part of the hydrogen of the acids is replaced by bases and part by acid radicals. Usually the acids and bases present do not completely saturate the colloids. When the colloids are separated from the water by filtration and allowed to become apparently dry at moderate temperatures, they still contain water, which is given off by decomposition when they are heated to dull redness. This is the combined water of the colloids. In addition to the combined water, bases, acid radicals, and colloidal acids, soil colloids always contain organic matter in varying quantities, some of which is presumably chemically combined with the inorganic matter and some presumably only intimately mixed with it. The whole of this material is sometimes called the colloid complex of the soil. It is unfortunate that because of the character of this complex it has as yet been found impossible to separate it into its individual components. For the most part these components are not soluble as a whole in any solvent, and none is volatile without decomposition at any temperature. The fundamental methods of purification by fractional crystallization and distillation therefore cannot be applied to them. The individual components can be arrived at only by inference from the behavior of the complex. In dry soils the clay and colloid may exist either as films on the larger mineral particles, as aggregates of the complex itself, or as more or less hard concretions. They serve as the binding material of soils.

The Soil Solution

The foregoing paragraphs have indicated that the soil is a very complex mixture of substances which in general persists from year to year without essential change except under special conditions. The components of this mixture must therefore, in general, be very insoluble in water. While this is true, at least some of the substances must be soluble to a limited extent if the soil is to serve as a means of transferring plant food to growing vegetation instead of serving only as a sort of framework for plant support. As a matter of fact, all the substances in soil are soluble to a limited extent in the soil moisture, which ordinarily surrounds the soil particles in humid regions, and indeed at intervals in any soil capable of supporting plant growth. The quantity of such dissolved material is always small at any one time even in the most fertile soils, and the concentration of the solution varies greatly with the quantity of water present. The materials present in the soil solution, as well as their quantity, vary also with the character of the soil.

If the soil solution is withdrawn from the soil by drainage and replaced by pure water or if the soluble materials are removed by plant growth, the supply of plant nutrients is continually renewed by the dissolving of more material from the soil. This renewal of plant nutrients in the soil solution is perhaps the most important function of the soil colloid. The best agricultural soils hold a sufficient quantity of the necessary plant nutrients to supply the requirements of the plants growing upon them unless the depletion is excessive by reason of crop removal, leaching, or erosive activities. The decay of vegetation assists in maintaining an adequate soil solution, since the mineral residues of plant decay return the plant nutrients to the soil in chemical forms particularly suited to the purpose. In cases of overcropping or other means of excessive depletion of available plant nutrients from the soil, restoration must be brought about by manures or artificial fertilizers.

Many soils used for agriculture contain insufficient quantities of clay and colloid; or the colloid is of such character that soil solutions adequate for plant growth are not produced. In such soils suitable nutrients must be added, if satisfactory plant yields are to be obtained. In such cases it is usually necessary

also to add the nutrients at frequent intervals. It is possible, however, to build up many depleted soils by means of fertilizers so that longer periods between fertilizer additions are practicable.

There are several methods of extracting soil solution from the soil, none of which is wholly satisfactory. When such soil extracts are obtained, it is generally found that the concentration of the soluble salts in the solution is less than is required in artificial nutrient solutions to produce corresponding results. It is also found that the soil solutions have a higher concentration of dissolved solids when the quantity of water present is small than when it is increased. Neither of these things should be true were the solutions made from pure salts in adequate quantity. It seems that in part at least these relations are to be ascribed to the presence of the colloids in the soils. In general, the concentration of any solution is usually greatest in the film adjacent to any solid surface, and none of the extraction methods satisfactorily remove all the soil solution adhering as a moisture film on the enormous surface areas presented by soil colloids. It is probable, however, that most of the effects of soil colloids upon solution are due to the behavior discussed later under the heading Base and Acid Exchange.

That the soil solution as such plays the dominant role in transferring soil material to plants is evident from the long-known fact that nutrient solutions can be prepared that will nourish plants and apparently furnish every essential except physical support and aeration. Recent large-scale experiments along this line have been extensively publicized, but yet it has not been fully demonstrated that such efforts promise economically practical results, at least when conducted out of doors.

Base and Acid Exchange

The soil colloids contain varying quantities of elements or groups of elements that by suitable treatment may be removed wholly or in part without destruction of the colloid complex. A part of these elements or radicals is believed to exist in the presence of water as ions, that is, as electrically charged particles similar to those of ordinary salt solutions, but with the difference that the free movement of the ions associated with the soil colloid is impeded by the presence of the insoluble colloid complex. The extent to which this separation of the soil colloid into ions takes place is chiefly dependent upon the colloid composition and the quantity of water present. If the ions present at any one time are removed, the colloid continues to ionize until for a given colloid no more ions can be produced.

One method that may be used to determine the quantity of material that may readily be separated from a soil colloid (the exchangeable bases and anions) is known as electrodialysis. To carry out this process the soil or colloid is placed in a suitably designed three-compartment vessel so that when a direct current of electricity is passed through the suspension of the colloid in water the positively charged ions are carried into one portion of the cell and there, through discharge of electricity and reaction with water, are converted into hydroxides of the metals. In this portion of the cell (the cathode compartment) are found the hydroxides of calcium, magnesium, potassium, and sodium and smaller quantities of other bases. The positively charged hydrogen ions of the colloids are released as gaseous hydrogen.[5] In another portion of the cell (the anode compartment) are collected the negative ions such as hydroxyl $(OH)^-$ and the negatively charged radicals of acids such as the phosphate radical $(PO_4)^{---}$, the sulphate radical $(SO_4)^{---}$, together with a little of the silicate radical $(SiO_3)^{--}$, which is able to pass through a membrane. Along with these are smaller quantities of such other negative ions as may exist in the colloid. These always include small quantities of the radicals of hydrochloric acid $(Cl)^-$ and of nitric acid $(NO_3)^-$. When these ions are discharged at the anode the hydroxyl ions form water and oxygen gas and the others the corresponding acids. When soil colloids are first subjected to this electrolytic process they are fairly good conductors of the current, and rapid removal of the ions occurs. As the process continues the removal slows down and eventually becomes very slow, with a corresponding decrease in current flow. In carrying out this process usually the greater part of the sodium and calcium of the colloid is removed at the cathode, and all the sulphate, chloride, and nitrate are removed at the anode.

[5] It must not be inferred from this statement that a hydrogen-free colloid residue remains in the middle chamber of the apparatus. As a matter of fact the residual colloid is of higher hydrogen content. This is because its reaction with water replaces the hydrogen ions and furnishes nearly all the hydroxyl ions for anodic current flow.

Only a small part of the magnesium and potassium is removed at the cathode and part of the phosphate at the anode.

This very brief and incomplete outline of electrodialysis is given here because it furnishes a background for the picture of the soil clay or colloid in water as made up of minute particles of insoluble material electrically charged and surrounded by various electrically charged particles consisting of the elements and radicals which when discharged and brought into solution give to the solution the plant nutrients that are not present as such. It also gives a picture of the renewal of this solution by continued ionization and discharge. If now the available plant nutrients in a soil are regarded as only those portions that may be brought into solution, it will be observed from the above discussion that by no means all the plant nutrients in a soil are immediately available for plant growth. This is particularly true of potassium and phosphoric acid.

A more commonly used means of estimating the available plant nutrients in the soil or its clay fraction, as well as of studying the chemical relationships of soils, is the determination of the exchangeable bases by means of extraction with salt solutions. It has long been known that if a soil or its clay is treated with a strong solution of a neutral salt such as sodium chloride ($NaCl$), barium chloride ($BaCl_2$), or ammonium acetate ($NH_4C_2H_3O_2$), and the suspension filtered, the filtrate will contain the chlorides or acetates of calcium, magnesium, and potassium, as well as of other like elements present in the soil. The elements so removed are collectively known as the exchangeable bases. Their kind and quantity are determined by the character of the soil and its previous treatment, and they are therefore a valuable indication of soil character and soil needs. Their removal from the soil by salt solutions is dependent upon the type of chemical reaction known as exchange and in soils may be indicated by the following schematic equation: $(H, Ca, Mg, K, Na)_3\ \text{clay} + 3\ NH_4Ac \rightarrow 3\ [HAc, CaAc_2, MgAc_2, KAc, NaAc] + (NH_4)_3\ \text{clay}$.

The materials indicated within the parentheses on the right-hand side of the above equation are in solution in water, and their quantities may be accurately determined. The sum of the hydrogen, calcium, magnesium, potassium, sodium, and other similar elements is chemically equivalent to the ammonium (NH_4) remaining with the colloid complex. These quantities are usually expressed as milliequivalents per 100 g of dry soil or colloid.

The quantity of ammonium remaining in the soil after the above-described treatment and adequate washing may be accurately determined and also expressed in milliequivalents of dry soil or colloid. (If other salts than ammonium acetate are used the same relations are found though the quantities are not always exactly the same.) This quantity, however determined, is known as the base-exchange capacity of a soil or colloid. The ratio between the exchangeable bases (exclusive of acid hydrogen) and the base-exchange capacity of a soil is known as the degree of base saturation of a soil or colloid. It is usually expressed in percentage. Thus if a soil has a base-exchange capacity of 30 milliequivalents per 100 g and the sum of its exchangeable bases is 10 milliequivalents, its degree of saturation is one-third, or 33⅓ percent. Very great differences are found in soils both with respect to their base exchange capacities and degree of saturation.

The normal soils of the humid areas in general have a low degree of saturation, which means that they do not have as much of the basic elements as they could retain were the leaching less by reason of lower rainfall. If, however, they have a high base-holding capacity and moderate leaching, they may have quite adequate storage of plant nutrients for maintaining plant growth under proper conditions of use. In the semiarid and arid areas the base-exchange capacity and degree of base saturation are both likely to be high, and no fertilizers are necessary except in the case of some particular soil deficiency due to local conditions. In such soils water supply is usually the limiting factor. Occasionally such soils may not only be saturated with bases, but an excess of water-soluble salts may be present to a degree that limits satisfactory use.

The soils and their colloids when in contact with water also have a part of their acidic content in the form of negative ions. Some of these are so readily liberated from the soil by moderate leaching that they are not found except in minute quantities in humid soils. In subhumid or arid soils they are likely to be found in larger quantities but by reason of almost complete removal by moderate leaching are not ordinarily considered as a part of the colloid of the soil. Examples are the negative ions of hydrochloric acid (Cl), nitric acid (NO_3), and others. In humid areas also the sulphate ion is retained to some degree by the soils of

low base-holding capacity and is normally present in the soils of both the humid and arid areas. In the latter case the presence of moderately soluble sulphates, such as calcium sulphate, leaves open the question of the degree to which the sulphate is a part of the colloid complex. In all fertile soils phosphates are present, and phosphate ions are produced by contact with water.

The behavior of the acid ions when the soils or their colloids are electrodialyzed or treated with very dilute acid is similar in type to the behavior of the bases and may be schematically represented by the following equation:

$$(H_2PO_4.SO_4.NO_3)\ \text{clay} + HCl \rightarrow (H_3PO_4 + H_2SO_4 + HNO_3) + \text{clay. Cl.}$$

It must be recalled, however, that since the colloid complex is amphoteric the treatment with hydrochloric acid also removes exchangeable bases through replacement by hydrogen. Here as with the base exchange the materials shown within parentheses on the right-hand side of the equation, however gained, are soluble in water, and the chloride-clay is not soluble in the presence of the hydrochloric acid. The mixture may be filtered and the acids present in solution determined quantitatively, although with continued washing chlorine is largely replaced by hydroxyl (OH).

For historical reasons not pertinent here, the quantities of acids found by electrodialysis or anionic exchange are often expressed not as acids or acid radicals but as oxides. For example, SO_3 instead of H_2SO_4 is used, P_2O_5 instead of H_3PO_4, etc. This is, of course, not true of such acids as hydrochloric acid or hydroiodic acid, in which the quantities of the elements are reported.

By no means so much is known of the acid-exchange relations of soils as of their base-exchange relations. This is probably because less decisive data have been obtained on acid exchange in relatively fewer investigations rather than because the subject is less important. The concentration of negative ions in soil suspensions is usually very low in humid soils. In relation to plant growth it appears that the most important of the anions is that of phosphoric acid, and it has been shown that soils hold phosphates in unavailable form when the soil colloids are high in content of iron oxide. It seems probable that this is because of the extreme insolubility of the phosphate of iron. Probably no portion of the field of soil research offers richer rewards than does that of the anionic relations of soils.

Hydrogen-Ion Concentration of Soils

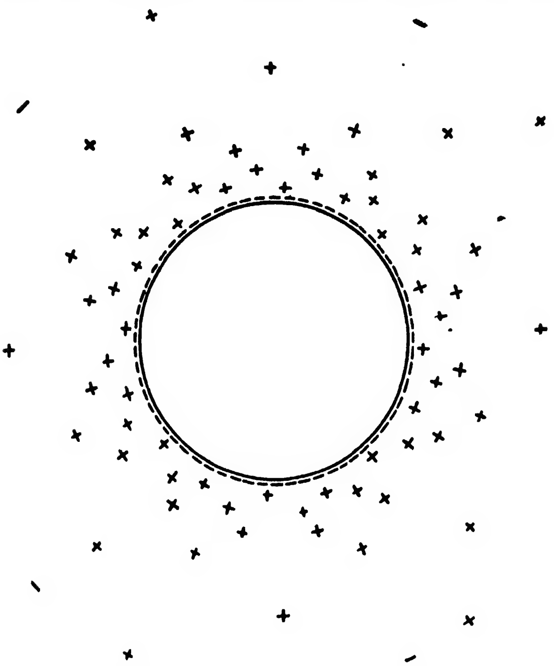
When a soil or its extracted colloid is mixed with water, the mixture becomes a conductor of an electric current, and it is therefore believed that ionization of the colloid complex occurs. Since, for the most part, the colloid is insoluble in water the colloid particles may be imagined as surrounded by a sheath of ions something after the order of the highly imaginative diagram shown in figure 2 (*312*). The dissolved ions are not wholly free, but part of them are held more or less closely in the neighborhood of the insoluble nucleus.

In all normal soils the predominating ions throughout the soil solution are those positively charged (cations). These include various metallic ions such as calcium and potassium as well as hydrogen ions, which are characteristic of acids. The electrical charges of these positive ions (cations) are for the most part balanced by corresponding negative charges on the immobile anions, which are the colloidal particles. It is probable that only a few of the exchangeable cations are actually dissociated at one time.

The relative quantities of the various ions as well as the total ion concentration in a soil suspension are largely determined by the character of the colloid and particularly by the kind of basic elements in the colloid. In soils of the semiarid and arid areas hydroxyl ions usually predominate over the hydrogen ions, owing to the quantities of bases present. Also other negative ions such as sulphate and chloride ionized from soluble salts are frequently present in these soils. As rainfall and attendant leaching are increased, hydrogen ions progressively replace such metallic ions as calcium and sodium, until in Podzol soils the influence of the presence of hydrogen ions is pronounced. But in the other soils such as Chernozem or Prairie, the plants return bases to the soil and prevent the development of a strongly acid condition.

In any case soil suspensions range from weakly acid to weakly basic, depending upon the character of the colloid. The degree of acidity, sometimes called the

soil reaction, is most simply indicated by the effect of the suspensions upon indicators such as litmus or similar more sensitive dyes that change color when made acid or alkaline. In the case of litmus, alkalinity of the soil is indicated by a blue color and acidity by a pink color when a paper stained with the dye is dipped into the soil suspension. The litmus indicator, once used extensively for determination of the degree of acidity (or alkalinity) has more recently been largely replaced by many other dyes. The acidity of the soil and the condition of the soil, particularly with respect to bases, which acidity connotes, are important factors in its adaptability to particular uses and in determining the necessary treatment. Acidity in its broader sense has been carefully studied, and a method of expressing it in simple terms has been developed that, while extremely technical, is now very frequently used in even the most elementary soil discussions.



+ CATIONS, INCLUDING HYDROGEN IONS
- ANIONS, INCLUDING HYDROXYL IONS

FIGURE 2.—Diagram of an imaginary colloid particles suspended in water.

In the simplest terms, whether a soil is acid or alkaline depends upon the presence in the soil suspension (therefore in moist soils) of an excess of hydrogen or of hydroxyl ions. These ions are both present in pure water in exactly equal though very minute concentrations. Expressed graphically, the relations are:

$$H_2O \leftrightarrows H^+(OH)^- \text{ and } \frac{H^+ \times (OH)^-}{H_2O} = \text{a constant}$$

where the quantities are 1 g of hydrogen ions and 17 g of hydroxyl ions in 10,000,000 liters of water. Ordinarily such concentrations are expressed in terms of the concentration of hydrogen ions, or their chemical equivalent, per liter where the unit is 1 g of hydrogen ions per liter. Therefore the concentration of hydrogen ions in pure water is $\frac{1}{10{,}000{,}000}$ or 0.0000001 of a unit concentration. To express exactly the concentration of such acids or bases as exist in soils and other substances of a like order of acidity would involve the use of awkward decimals or fractions. Consequently a system has been evolved for the more convenient expression of such small concentrations.

The concentration of hydrogen ions in pure water, as stated, is $\frac{1}{10{,}000{,}000}$. The logarithm of this number is -7, and any acid or base concentration may be compared in terms of this logarithm. The various values are called pH values, a term adopted without explanation of its derivation by a Danish scientist, S. P. L. Sorensen, and now in common use. Expressed in a slightly different way, the pH values of weak acids or bases are the logarithms of the reciprocal of the hydrogen-ion concentration. The hydrogen-ion concentration of water in terms

of pH is therefore 7; any aqueous solution more acid than water has a lower numerical value than 7; and any solution less acid than water will have a pH value greater than 7.

The numerical expressions developed are as follows: A soil having a pH value of 6 is a very weak acid but has 10 times the concentration of hydrogen ions present in pure water. Soils having a pH value of 5, 4, 3, and 2, respectively, are 100, 1,000, 10,000, 100,000 times as acid as water. No soils of lower pH values are known, but if one were found of a pH value of 1 or 0 the relative acid strength would be 1,000,000 and 10,000,000 times that of water. Since as hydrogen ions decrease in water the hydroxyl ions must increase correspondingly, it follows that a soil suspension having a pH value of 8 is 10 times more concentrated than pure water in respect to hydroxyl ions and this rate increases with increase of pH values until at a pH value of 14 the soil suspension would have 10,000,000 times the concentration of hydroxyl ions present in pure water. No normal soil approaching this pH value is known. Indeed the range of pH values of arable soils is normally between the limits of 4 and 9. This form of expression of soil acidity or alkalinity is used merely for the convenient expression of soil reaction in whole numbers. When acid or alkaline concentrations beyond the range of the pH scale are encountered (they never are in soils), the more ordinary modes of expression of concentration used in science are employed.

It is beyond the scope of the present discussion to enter into detail concerning the methods used in technical laboratories for the exact determination of the pH values shown by soils. A number of different schemes are employed for preparing a suitable device for making these measurements. Details are given in a circular published by this Department (*371*).

One method for determination of the approximate pH values of soils has extensive application. It is the use of a series of soluble dyes each of which changes color within a narrow range of pH values. There is a sufficient number of these to cover normal soils. These sets of dyes and corresponding color charts are marketed by various firms either alone or with other devices for making approximate estimation of fertilizer needs (*16*).

While agricultural soils may have pH values between the limits 4.0 and 9.0, the great majority of surface soils under cultivation actually have values between 5.0 and 7.5.

The chemical factors underlying the relation of soil pH value to plant growth are complex. Some plants appear to be affected directly by the intensity of acidity. In other cases, a more important factor is the lime content or the calcium-ion concentration, with which pH value is usually correlated to some degree. As bases, particularly calcium, are leached out or taken up by plants, hydrogen ions take their place in the soil colloid. Sometimes, however, the simpler calcium compounds such as calcium sulphate may provide an adequate concentration of calcium ions for various plants in a somewhat acid soil. Furthermore, an increase in the hydrogen-ion concentration (lower pH) tends to increase the solubility of aluminum. This is frequently a detrimental factor. The presence of free calcium carbonate, ordinarily desirable, which normally accompanies a soil of pH 7 or greater, is ruinous to certain plants, presumably in part at least because it prevents an adequate quantity of iron or other essential ions from dissolving in the soil solution. Soil acidity may vary to a detectable degree in a particular soil in different seasons of the year; it may be altered by growing plants and by the decomposition of organic matter. The continued use of certain fertilizer constituents may have a marked influence upon soil pH value. Such changes are sometimes beneficial and sometimes detrimental, depending upon the character of the soil and the crops to be grown.

It is in general true that a soil of low pH value is deficient in bases or other plant nutrients. It should be mentioned also that the normal pH value of a soil is dependent upon the character of the soil colloid as well as upon the degree of base saturation of the colloid. For example, a completely debased colloid of a lateritic soil may have a pH value much higher than a completely debased colloid of such soils as the Chernozem or Gray-Brown Podzolic group. pH values taken alone are therefore not indicative of comparative impoverishment of soils except within narrow limits of soil types.

Excessively high pH values of soils are also indicative of unfavorable soil conditions, particularly as regards the difficulty of percolating water through them. Frequently, the high pH value of a soil is due to the presence of soluble salts, a

condition that can sometimes be remedied by leaching. Sometimes it is due to the presence of base-saturated clays, especially sodium clay, in which case remedial leaching can be hastened by adding calcium salts to the water used.

It should also be mentioned that the pH values shown by soils bear no direct relation to the total acidity of the soil. This latter quantity is measured by the difference between the total base-exchange capacity and the quantity of bases liberated by electrodialysis or some other exchangeable-base method of measurement. It is for this reason that pH determinations alone do not furnish sufficient information for determining the lime requirement or other remedial measure for securing a desired pH value. From the chemical standpoint, lime requirement means the quantity of lime necessary to bring a soil to a definite arbitrary pH, such as pH 7. However, since the lime requirement of plants differs widely, this term has a varying agricultural significance.

Classification of Colloids

There is as yet no general agreement concerning the composition of the individual components present in any given colloid. Different views exist because of the present inability to isolate these components. There is no dispute, however, concerning the differences in composition of colloids as shown by analyses.

If the relative quantities of silica and of iron oxide and alumina are expressed in chemical equivalent quantities, it appears at once that markedly different quantities of the constituents characterize the colloids of the different soils. This ratio, the silica-sesquioxide ratio, is obtained by dividing the percentage amounts of the constituents by their formula weights of the constituents and then comparing the resulting quotients by dividing the equivalent of the silica by the sum of the equivalents of the alumina and iron oxide.[6] The colloids of the various soil groups have widely varying relative quantities of these components. In a similar manner the relative quantities of silica and alumina and of silica and total bases are shown to vary between wide limits.

It will be observed that the colloids of the Chernozem soils have essentially the same colloid composition throughout the profile, or at least to the depths examined. The same is also true of the soils belonging to the lateritic group. There is, however, a wide difference between the composition of the colloids of the two groups, as indicated by the silica-sesquioxide, silica-alumina, and silica-total base ratios and the combined water.

From the analyses and derived data of the Podzol colloids it has been found that there are wide differences of composition in the various horizons. The A horizons have relatively high silica ratios and the B horizon low ratios. The combined water is low in the A horizons (when the organic matter is low) and high in the B horizon. In studying these relations it may be observed that in the Prairie soils are found values intermediate between the Chernozems and the lateritic soils. In the Gray-Brown Podzolic group the ratios in general lie between those of the Podzols and the lateritic group. In the case of the Laterites, of which examples are found only outside the continental limits of the United States, the characteristics of the lateritic soils are accentuated.

The primary purpose in presenting the points just made is to draw two inferences: (1) The relationship shown between composition of the colloids and the field classification of soils emphasizes the dependence of the essential soil characteristics upon the character of the colloid; (2) from the wide variation in colloid composition it can be concluded that no blanket specifications for agricultural practices can be justified. It is especially to be noted that the quantity of colloid found in soils bears no direct relation to its composition. In each of the great soil groups wide textural variations are found. In general, however, the surface soils have less colloid than the B horizon of the same soil.

[6] In any elementary chemistry textbook can be found the atomic weights, from which the various formula weights involved here are readily obtainable. Let us assume that a colloid contains 45 percent of silica (SiO_2), 25 percent of alumina (Al_2O_3), and 10 percent of iron oxide (Fe_2O_3). The respective formula weights are 60.1 for SiO_2, 101.9 for Al_2O_3, and 159.7 for Fe_2O_3. The quotients from division of percentage by formula weight are then $\frac{45}{60.1}$ or 0.748 for SiO_2; $\frac{25}{101.9}$ or 0.254 for Al_2O_3; and $\frac{10}{159.7}$ or 0.062 for Fe_2O_3. The silica-sesquioxide ratio would then be $\frac{0.748}{.254+.062}=2.37$.

Other Soil Properties Determined by Colloids

Many, though not all, of the important agronomic characteristics of soils depend upon the quantity and kind of colloid present and upon the state of aggregation of the colloid. It will be possible here to point out only a few of these relations for the primary purpose of showing that intelligent soil use must be based upon knowledge of colloid behavior. It is not essential that this knowledge be gained from books. Experience is an excellent school even though expensive. Proper treatment of soil, so far as it is followed, has been learned for the most part through age-long experience with soils.

The swelling of soils when moistened is caused almost wholly by the absorption of water by the colloid, and its extent with any given soil type is roughly dependent upon the quantity of colloid present. Colloids from widely different sources not only swell to different degrees, but the resulting wet masses of soil possess very different properties.

Of course the shrinkage of soils on drying is the result of the loss of the moisture absorbed in the swelling process, and there are many differences in the resulting dry masses that are dependent upon the quantity and kind of colloid. These differences show themselves most markedly through the behavior of the soils on being worked when considerable water is present in them. The Laterite soils can be plowed when wet and will be friable when they dry out. On the other hand, soils with colloids of high silica-sesquioxide ratio and a high colloid content, such as the Prairie soils and Chernozems, behave very differently. If worked when wet they become puddled very readily and dry out to form highly compacted clods. The soils with colloids of high silica-sesquioxide ratio, such as the Prairie, Chernozem, and semiarid soils, also behave very differently when they are saturated with different bases. If the dominant basic element present is calcium, they tend to dry to a friable mass when worked at moderate moisture content. Sodium-saturated clays dry to unworkable hard clods. Such soils are also difficult to irrigate because their high swelling coefficient quickly stops further ingress of water, that is, they "freeze" at the surface. There are also marked differences in the behavior of soils toward erosion that depend upon the character and quantity of colloids.

Perhaps the most important soil property that is dependent upon colloid composition is the base-holding capacity. In general it may be said that soils of high base-holding capacity are those in which the colloids have a high silica-sesquioxide ratio, and unless subject to excessive leaching with water, as in the case of the Podzol soils, they have also a high exchangeable base content. They therefore have soil solutions, with adequate moisture, that are favorable for plant growth so far as their base content is concerned. Such soils ordinarily need no artificial supply of plant food or stimulant to plant growth, except the addition of phosphate in certain areas. Since the soil solution at any one time holds in solution only a very small fraction of the available plant food, the supply is continually renewed by the action of water upon the colloid. Such soils are regarded as permanently fertile. Of course this is true only in a very limited sense. In the areas where rainfall is high or the soils are shallow or both, such colloids may have been impoverished in plant food, and natural or artificial fertilizers are essential for the practice of successful agriculture. This condition holds particularly in the areas of Podzol soils and to a lesser extent in the areas of Gray-Brown Podzolic soils. In the Gray-Brown Podzolic soils the depletion of plant food may be remedied to a large degree by manuring and the use of artificial fertilizers. To a considerable extent the effects of such treatment may be carried over from one year to successive years. Also to a considerable degree normal erosion contributes to the maintenance of fertility by removing thin films of leached material, thus exposing new soil parent material for incorporation with the soil.

Contrasting conditions are found in those soils in which the silica-sesquioxide or silica-alumina ratios are low (the Laterites and lateritic soils). In such soils the silica-total base ratio is very high, i. e., the plant food reserves of the soil are very limited, and the soils have low base-holding capacity and are low in exchangeable bases. They therefore furnish inadequate soil solutions over any extended period. Such soils may be in a state of high fertility in case the organic matter of the colloid is large, since in general organic colloids have high base-holding capacity. But under cropping conditions in such areas as produce soils of these types (hot, moist climates) the organic matter quickly decays and disappears. The plant-food needs of normal crops must therefore be supplied by frequent applica-

tion of fertilizers. It is impossible for Laterite soils to keep bases in reserve supply to be slowly doled out to the plants by way of the soil solution. Instead the greater portion of unused bases of fertilizers is likely to be carried away by the first heavy rain. The same conditions exist to a less marked degree in the lateritic soils. In such soils no rebuilding of the soil is possible, but fertilizer requirements must be met through a dole system of frequent applications. In the lateritic and Laterite soils an additional colloid relationship presents itself in the fact that certain acid radicals, and in particular the highly essential radical of phosphoric acid, form very insoluble salts with certain colloid components. It is possible, therefore, for phosphorus deficiency to exist even when phosphates are present in large amounts. It even happens that soils of lateritic types may have more phosphates than are quite adequate for soils of higher silica-sesquioxide ratios and yet require additions of phosphates. It is probable that the unavailable phosphates of soils exist for the most part as insoluble salts of iron and aluminum.

Limited space forbids the detailed discussion of many other relations between soil behavior and the colloid composition. It seems certain that all the elements existing in traces in the soil exist as part of the colloid complex and behave in general as do silica, iron, and aluminum on the one hand or the more basic and acidic elements or radicals on the other. It is believed that sufficient evidence is available to warrant the statement that the same general chemical relations apply to soils and their colloids as are to be expected of any mixture of relatively insoluble substances that are amphoteric, that is, that possess both acidic and basic character; and that the colloids are as a rule partially saturated salts of such compounds. It is also clear that these colloids are of almost infinite variety but that the variations are such that they may be classified in a systematic fashion.

It is essential then that the composition of a given soil and more particularly of its colloid be accurately known in order most effectively to adapt its treatment to its primary use, the production of crops. It should be apparent from what is known that no single system of agriculture is suited to all soils but that adaptation of practice must depend upon soil character. At the same time it is recognized that only a start has been made in the systematic study of soils and that there is need of intensive study of soil chemistry in order to make completely clear the underlying causes of the physical and chemical properties of the soil. The results of such research will provide a more fully coordinated body of knowledge that will permit better soil conservation and soil use.

ONE of the most important things in the soil is humus, the product of decayed organic matter. This article discusses soil humus from the broadest standpoint, telling what it is; what its functions are; what factors determine whether the supply is large or small and whether it is slowly or quickly used up; how different types of soil differ in their humus content; how humus is related to the productivity of the soil.

Soil Organic Matter and Soil Humus

By Constantin C. Nikiforoff[1]

THE fundamental characteristic of soil is its productivity; that is, its capacity to produce green plants. The plants, during a period of their growth, absorb and accumulate a certain amount of the radiant energy of sunlight and convert it into a form available to other living organisms, which are incapable of utilizing the energy of the sunlight directly. Living matter, including, as it does, the sum total of all living plants, animals, bacteria, etc., is unique among the formations of the earth. It possesses a number of peculiar features not found in nonliving matter, such as a dissemination of its mass in a multitude of individual organisms, a capacity for endless self-renewal by means of reproduction, and a marked adaptability to environment.

It has been assumed that the amount of living matter on the earth remains more or less constant, and it can further be assumed that this amount is limited by natural conditions at the earth's surface, such as temperature, air pressure, and amount of available water. Within the limits fixed by these factors the earth's surface may be said to be saturated by living matter. The distribution of the latter over the surface area, however, is very uneven, depending upon local conditions. The regions where natural conditions are favorable for life harbor conspicuous congestions of living matter, whereas regions of the opposite type appear as virtual biological vacuums.

Every natural province or landscape[2] is characterized by its own concentration of living matter, or so-called biological pressure. Biological pressure represents the relationship between the amount of

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[2] The word "landscape" as used in soil geography means the sum total of the characteristics that distinguish a certain area on the earth's surface from other areas. These characteristics are the result not only of natural forces but of human occupancy and use of the land. Included among them are such features as soil types, vegetation, rock formations, hills, valleys, streams, cultivated fields, roads, buildings. All of these features together give the area its distinguishing pattern, which is the landscape.

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living matter and the surface area; its intensity can be expressed as the total weight of living matter per unit area or by the variety and number of organisms per unit area. The biological pressure of every natural landscape (note the word "natural") is in equilibrium with the potential capacity of the region for the reproduction and support of life.

The exact composition of living matter is not known. It is known, however, that living matter is made up of many elements, the bulk of which consists of carbon, oxygen, hydrogen, and nitrogen. Water is one of the most important constituents of living matter, both as to function and as to bulk. The development, the functions, and the very existence of organisms depend largely upon a sufficient supply of moisture. Relative intensities of biological pressure correspond very closely to the amounts of available moisture, provided other conditions, such as temperature and supply of mineral nutrients, remain relatively constant. Irrigation of many arid regions, for example, has demonstrated that the actual biological pressure of such areas is considerably lower than the potential pressure because water is deficient.

Because of the rather narrow limitation of the total amount of living matter on the earth and because of its repeated turn-over during long geological eras, the elements that comprise it must pass through constantly recurring cycles. A certain amount of living matter, whether whole organisms or only certain parts of them, is continually dying and decomposing into its elemental constituents. At the same time, equal amounts of living matter are being synthesized anew in the growth of new generations. Endless successions of generations have deposited their residues in the soil, from which soil organic matter and soil humus have been formed. In spite of the continual depositing of residues, neither the soil organic matter as a whole nor the humus portion of it accumulates endlessly. They are both unstable and gradually decompose into the simple elemental constituents.

COMPOSITION OF SOIL ORGANIC MATTER AND SOIL HUMUS

The bodies of dead organisms and the residues of living matter deposited on and within the soil form the material known as soil organic matter. Soil organic matter theoretically comprises only the dead residues of organisms and the various products of their decomposition. It is practically impossible, however, to separate this material from the living micro-organisms that inhabit the soil and perform the task of decomposing the residues. The bulk of the bodies of micro-organisms, together with their own residues, is therefore commonly regarded as a part of soil organic matter. This matter includes the dead roots, leaves, fruits, and stems of plants; carcasses of insects, worms, and animals; live and dead bacteria, fungi, and protozoa; various products of decomposition of the dead residues; and the newly synthesized substance of active micro-organisms.

Chemically, soil organic matter represents a mixture of a great many different substances which can be classified into three groups: (1) Carbohydrates, (2) protein, and (3) fats, resins, waxes, and similar compounds. The gradual decomposition of these organic substances into the most simple mineral compounds is spoken of as mineraliza-

tion. The ultimate end products of mineralization are principally water and carbon dioxide and smaller amounts of free nitrogen, ammonia, methane, etc., and a few simple mineral salts. The process of mineralization, or reduction of the fresh residues to the simple end products, proceeds gradually with the formation of a number of intermediate substances. Some of these are products of the decomposition of the original material, and others are the result of resynthesis. Sooner or later the entire amount of organic residues turned over to the soil in any given time undergoes complete mineralization.

Soil humus represents a stage in the decomposition of soil organic matter. Organic residues as a whole do not decompose uniformly. Some substances decompose rapidly and are reduced to their elemental constituents in a short time; other substances are more resistant to decomposition, and the process of their mineralization may extend over a period of many years. The resulting mixture of many different compounds formed during the decomposition processes is humus. It has no definite chemical composition, but physically it is a homogeneous, amorphous, dark-colored, and practically odorless material. Fresh organic residues, as well as those in an advanced stage of decomposition which still preserve a specific structure of the organized tissues, are not considered a part of soil humus, although they are sometimes referred to as raw humus.

ACCUMULATION OF HUMUS IN THE SOIL

Soil humus is not a stable material. As the organic matter decomposes, new humus is continually being formed, and part of the old is being completely mineralized. The equilibrium between the two processes determines the amount of humus present in a soil at a given time.

During the development of a young and immature soil the amount of new humus annually added is greater than the amount undergoing mineralization, and a gradual accumulation occurs. As the soil develops and approaches maturity, the absolute amounts of humus undergoing mineralization gradually increase until they equal the amounts of newly formed humus. From that time on, the two processes—formation and mineralization—proceed at an equal rate, and the soil may be said to have reached a state of maturity or one of equilibrium with its natural environment. The average content of humus in the mature soil remains relatively constant as long as no change in natural conditions occurs. Any change in the natural conditions that upsets the equilibrium will be followed by a corresponding change in the humus content of the soil.

A great many profound changes of natural environment are caused by man. To mention only a few of the more spectacular meddlings with nature, irrigation of arid land, drainage of wet land, deforestation, annual removal of crops, and the breaking of sod all lead to a rapid and marked change of the humus balance of the affected soil. The stability of the new soil conditions depends entirely on the stability of the changes effected in the environment. As a general rule, nature sooner or later tends to obliterate all these changes and to reestablish her own ways. Reestablishment of the old balance, however, usually takes a much longer time than it did to accomplish the striking changes produced by artificial processes.

FUNCTIONS OF HUMUS

The function of humus in any soil system and its significance for maintenance of the productivity of the soil is determined by its dynamic character. Humus is not a mechanical accumulation of static or inert material. It represents a certain stage of an endless turn-over or exchange of certain elements between living matter and the mineral kingdom. The gradual, rather slow mineralization of humus continually liberates a certain amount of simple mineral compounds in forms available for consumption by growing plants.

A certain supply of mineral nutrients in available form is essential for normal development of living matter. The weathering of minerals in the earth's crust liberates the original supply of these simple compounds, but at the same time part of them are carried away in drainage waters and finally find their way to the ocean. Living matter absorbs a part of these materials, thus preventing their rapid and complete removal. This mineral material in dead organic matter—so-called ash material—is included in the soil humus and is gradually liberated in a form again available to plants as the humus decomposes. Soil humus, therefore, appears as a storeroom of the mineral plant nutrients and as a regulator of their supply to the growing crop.

The significance of humus in soil is not limited to its function as a conserver of mineral plant nutrients and a regulator of their liberation. Humus modifies such physical and mechanical properties of the soil as structure, color, consistence, and moisture-holding capacity to a very great degree. For example, the formation of the granular structure most favorable for the development of crop plants is governed by the content of humus in the soil.

FACTORS GOVERNING CONTENT AND NATURE OF SOIL HUMUS

The absolute content of humus in different soils varies greatly. The amount is a function both of the original quantity of humus-forming material per unit area and of the rate of decomposition. The former naturally depends upon the volume of living matter returned to the soil in the form of organic residues, whereas the latter is a function of the quality of the residues and of the energy and activity of the soil micro-organisms and other decomposing agents.

The greatest content of humus in a soil is not necessarily associated with the greatest production of living matter. In many regions a high biological pressure is accompanied by an exceedingly strong activity of the decomposing agents, so that the organic residues undergo very rapid mineralization, with the formation of little, if any, true humus. The relatively low humus content of forested tropical soils can be cited by way of illustration. In direct contrast with the tropical regions are the typical grasslands, where a moderate biological pressure is combined with a slow and gradual decomposition of the residues—a condition that leads to the formation of an enormous amount of humus in the grassland soils.

The bulk of organic residues in every soil is furnished by plants. Consequently, the general character of vegetation will be a major factor in determining the quantity, distribution, and general quality

of soil organic matter, including humus. The geographical distribution of plants, in turn, depends upon climatic conditions. Climatic conditions will also affect the ecology [3] and energy of the micro-organisms and thus influence the general direction and velocity of mineralization.

Conditions of climate, the general character of plant associations, and the activity of micro-organisms collectively determine the nature

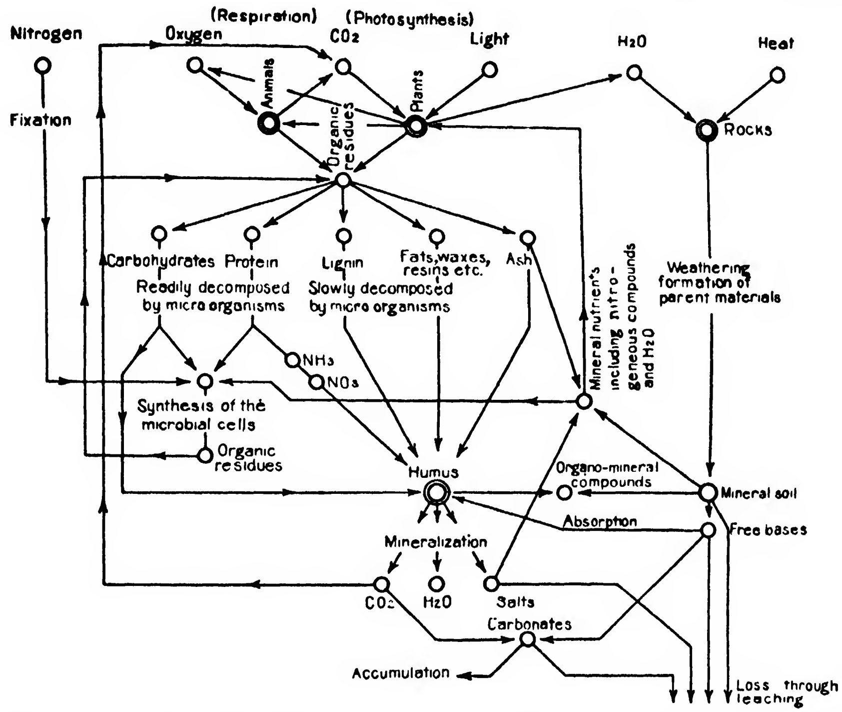

FIGURE 1.—The relationships between the various processes concerned with synthesis and decomposition of humus in the soil.

of the cycles through which elements will pass as they are taken up from the soil, become incorporated in living matter, and finally find their way back to the soil again. Cycles will be either short or long, fast or slow, depending on the combination of the above factors. Large or small amounts of substances will be involved, according to whether vegetation is rank or sparse. Decomposition of residues will be rapid and complete or slow and partial or will vary with the seasons as the temperature, water supply, and types of organisms vary. The nature of the cycle, or the relationship between living matter and the soil, will determine the character of the soil humus and the fundamental properties of the soil as well.

Two very definite consecutive phases may be differentiated—one a synthesis of organic matter by living organisms; the other, a decomposition and mineralization of this material in the soil (fig. 1).

[3] Ecology refers to the mutual relations between living organisms and their environment.

The cyclic character of the exchange of substances between the soil and living matter and the relative constancy of the amounts of material involved does not mean that the same substances circulate endlessly through living matter and soil humus. A certain amount is constantly escaping and being lost to the cycle, some of it being leached from the soil, some being lost to the atmosphere, and some being fixed as insoluble mineral complexes. Such losses are offset by the introduction of like quantities of similar material from different sources. Mineral nutrients are provided by a ceaseless decomposition of mineral constituents of soil; nitrogen is extracted from the air by the nitrogen-fixing micro-organisms; and carbon dioxide is fixed by means of photosynthesis.[4]

The principal agents of decomposition comprise a great variety of living organisms, which can be classified into three general groups: (1) Higher organisms, mostly of the animal kingdom, (2) bacteria, and (3) fungi. Most of the higher organisms consume the fresh material and leave the partly decomposed products in the form of excreta, which are broken down by micro-organisms. The amount of decomposition performed by higher organisms can be illustrated by citing the devastations caused by locusts and grasshoppers, the work performed by earthworms, and the volume of crops harvested and consumed by man and his domestic animals.

It is not yet known precisely how the process of decomposition of residues by fungi differs from that performed by bacteria. It is generally assumed, however, that the residues of forest vegetation are decomposed chiefly by fungi and that those of grasslands are decomposed mostly by bacteria.

HUMUS UNDER DIFFERENT TYPES OF SOIL FORMATION

The three principal types of soil formation—those occurring in grassland, woodland, and shrub land—are characterized by particular equilibria between the soil and life upon it. Differences in type of vegetation, for example, or in the nature and rate of decomposition of organic residues exist between the particular soil types that have developed in and are characteristic of the various regions.

In addition to the three principal types of soil-forming processes outlined below, there are several others resulting from combinations of different types of vegetation, for example, forest and grass, forest and shrubs, shrubs and grass, etc. All these occupy intermediate positions as to content and distribution of humus within the profile, depending upon the relative dominance of one soil-forming process.

In Grasslands

The grassland type of soil formation is associated with the subarid and moderately warm climatic provinces; vegetative periods alternate with cold wintry ones, as a rule, although the two may be separated by a short dry season, which terminates plant growth prior to the first killing frosts. Under this regimen, practically the entire mass of vegetable material produced by the annual crop is turned

[4] Photosynthesis is a process whereby green plants utilize part of the energy of sunlight to synthesize carbohydrates such as sugar from carbon dioxide and water.

over to the soil in the form of dead organic residues. Only seeds and the reproducing organs of biennials and perennials survive. The fibrous grass roots are concentrated in the upper 6 to 12 inches of the soil and form a more or less compact sod. The dry grass, killed by the late summer drought, is not detached from the roots but lies on the surface, forming a soft mat, which is covered and somewhat compressed by the snow in winter.

Very little decomposition of either tops or roots occurs during the winter, but a vigorous activity of the micro-organisms develops during the next spring simultaneously with the beginning of the vegetative period. Substances in the residues, such as cellulose (cotton is an example of nearly pure cellulose) and hemicellulose (substances less complex than cellulose and readily broken down to simple sugars) decompose rapidly and disappear from the soil in a short time. Other substances, such as lignin (a principal component of woody materials, which gives them rigidity), decompose slowly and may persist in the soil for many years. The general process of decomposition of the organic residues, therefore, seems to proceed rapidly at first but gradually slows down, leading to the formation of a large quantity of true humus. Because of the slowing down, the turn-over of material from living matter through soil humus to the final end products is not complete before the next cycle begins. Every new cycle beginning in the spring overlaps various phases of the preceding cycles, which naturally leads to a formation of humus complexes. In a mature soil balanced with its environment, the annual income of fresh humus equals the amount lost through mineralization. The humus content of a soil is thereby maintained at a constant level despite continual replacement.

Under Forest

The relationship between living matter and soil humus under a forest type of soil formation differs from that in grasslands in the nature of the cycles through which the elements pass. Under woodland there are at least two fundamentally different subcycles. Part of the living matter is turned over to the soil annually and part at longer but irregular intervals. The annual return of organic matter to the soil consists of dead leaves, needles, cones, and small branches, all of which are deposited on the surface. Here they are combined with mosses, lichens, ferns, mushrooms, and a few grasses to form a soft, fluffy layer which is permeated by mold and the roots of shrubs. All this material remains on the surface of the soil. The organic residues in the form of dead roots annually turned over to the soil and distributed within it (below the surface) comprise a small part of the total mass of residues of the forest vegetation. The residues of the tree roots are not concentrated in any narrow soil horizon. like most of the roots of the grass vegetation. Therefore the relative amounts of organic matter and humus formed from these residues are much less in proportion to the mineral part in forest than in grassland soil. The general nature of the subcycle through which the annual leaf fall passes—to soil humus, through mineralization, and back to living matter again—is more or less similar to the cycle that prevails in grasslands.

A second part of the living matter of forest vegetation goes through a much slower cycle before it again becomes living matter. The trunks and roots of trees do not die annually but fix a considerable amount of gradually growing living matter for many years. In addition to retaining substances in their structures for long periods while growing, the fallen trunks of dead trees decompose slowly and remain on the surface of the soil for many more years, after being covered by moss and the blanket formed on the forest floor. The rotten woody material resulting from the decay of trees and their roots is added to the mass of the forest floor and at times gives it a rather bright-brown or coffee-brown color.

The process of mineralization of all the different kinds of debris on the forest floor requires many years for completion. Advance stages of decomposition of the older residues, therefore, may be overlapped by the first stages of decay of more recent deposits, and the older residues themselves may be covered by the less decomposed ones of the more recent cycles. Very little true amorphous humus is produced under forest, for several different reasons.

It has been found that the humus of forest soil is less resistant to further decomposition than the humus of grassland soils. It would seem very likely, therefore, that the entire process of mineralization of residues under forest does not take so much time as under grassland but is completed in a comparatively short period. It can also be assumed that most of the forest residues decompose more directly into the simplest end products, with the formation of less true humus. Finally, a more diffuse distribution of organic matter occurs in forest soils, since the tree roots are not concentrated in any comparatively shallow horizon but are scattered throughout a much greater thickness of soil. All these conditions and possibly others are responsible for the much lower content of humus in forest soils than in grassland soils and may explain the fact that most of the soil organic matter in the forest consists of the semidecomposed raw humus, whereas in the grassland soil most of it is in the form of the true humus.

In Deserts

The shrub-land type of soil formation includes two different subtypes, the cold desert, or tundra, and the hot desert. Very little is actually known about the soil-forming processes of the tundra except that the vegetative period is short and that general conditions are too severe for the development of large amounts of living matter. The annual income of organic residues to the soil is rather small, but it is accompanied by a slow decomposition, due partly to the weakness of the micro-organisms and partly to the shortness of the season during which biological activity takes place. Consequently the organic matter of the tundra soil is mostly in the form of raw humus, which forms a peaty cover (moss peat) on the surface of the mineral soil.

In the hot desert there is very little if any interruption of the period of possible vegetative growth by frost. The short cold period, where it does occur, is preceded by a long droughty season, which terminates the growth of plants far in advance of killing frosts and reduces the vegetative period of the spring and early summer to a very short interval. Only a small amount of organic material is annually pro-

duced and turned over to the soil. The heat of the dry season, which terminates vegetative development, does not arrest the activity of the micro-organisms but probably stimulates it. Decomposition is thereby hastened to such an extent that the annual residues are completely gone long before the next period of vegetative growth. This naturally precludes the possibility of humus formation and leaves the desert soils very poor in organic matter. The organic residues left by the desert plants on the surface of the soil consist mostly of small, hard, but brittle leaflets and stems, which are easily detached and carried about by wind. The roots of plants must be spread through a considerable depth of soil to obtain moisture, consequently no relative concentration of the organic matter occurs in the profiles of these soils.

DISTRIBUTION OF HUMUS IN THE SOIL

Distribution of the humus within the profile is governed largely by distribution of the original organic matter, but some movement of humus may occur.

By far the greater part of organic residues is naturally deposited on the surface of the soil, so that the maximum content of humus occurs at the very top of the soil profile with only rare exceptions. The organic residues within the soil consist chiefly of dead roots; carcasses of dead animals, insects, and worms; organic material brought into the soil from the surface by its population; and the micro-organisms. In some instances the total amount of organic matter of roots (especially of grasses) cannot be much less than that of the aerial parts, but as a rule the distribution of roots is so diffuse that the relative percentage of organic residues per unit volume from roots is less than that accumulated on the surface of the soil.

Normally the content of soil organic matter, and particularly humus, will be greatest near the surface of the soil and will decrease with depth until it disappears entirely. Soils formed under grassland are characterized by a very gradual decrease of the content of humus in passing to the lower horizons, whereas in the soils of the woodland type there is a rather sudden and sharp decrease in organic matter very close to the surface. Annual deposits of organic material in the forest consist principally of the residues deposited on the surface (leaves, needles, cones, etc.), and roots supply a relatively small proportion.

The solubility of soil humus in water is very low; usually only a fraction of 1 percent of the total mass of humus is in a water-soluble form. Very little shifting and distribution of humus in the soil body occurs in connection with the movement of soil solutions. Much greater quantities of humus are moved from the points of origin mechanically and in suspensions. It can be assumed that a large part of the humus in the deeper horizons of Chernozems and other grassland soils has moved down from the surface by infiltration.

Humus Content

The content of humus in the upper horizon of the American Chernozems, such as those of Kansas, Nebraska, and the Dakotas, varies from about 5 to more than 10 percent. The horizon with a high content

of organic matter varies in thickness from only a few inches to more than a foot. Downward the content of humus gradually declines; occasionally, however, the soil may contain more than 1 percent at a depth of 3 or more feet.

A calculation of the total amount of humus in certain Chernozems of Nebraska and the Dakotas shows that 1 acre of this soil may hold from 120 to more than 240 tons of humus. In other regions of the world, Chernozems are known that contain from 400 to about 600 tons of humus per acre. The amount of organic matter in the form of humus in a black grassland soil can be many times greater by weight or volume than the amount of the best crop of living matter grown on that soil. Such a relation between the quantities of organic matter in the form of living matter and of soil humus indicates that the process of mineralization of humus in these regions is exceedingly slow and that the humus stores a great reserve of the plant nutrients.

The average carbon content of humus is 56 percent, and the carbon-nitrogen ratio is about 10 to 1. The ash content of humus, containing the phosphorus, potassium, sulphur, and many other elements, is variable but is known to be somewhat higher than that of the residues from which the humus is formed. The content of ash in herbaceous plants varies between 5 and 7 percent. Therefore it may be assumed that 1 acre of Chernozem soil holds from 60 to 300 tons of organic carbon, from 6 to 30 tons of nitrogen, and a reserve of 6 to 30 tons of different mineral plant nutrients well protected from waste by leaching.

The content of organic matter in the soils of the forested belt is considerably lower than that of the grassland soils. The calculation of the amount of such material in the forest soils of the Eastern and Northeastern States shows that it varies from less than 40 to about 80 tons per acre. These figures, however, do not represent the quantities of true soil humus. A large part of this material, more than half of it in many instances, is composed of partly decomposed residues, which form a layer of raw humus on the surface of the soil. The amount of true humus in forest soils probably varies from about 20 to 50 tons per acre. The quantity of organic matter in forest soils is much less than that of the living plants supported by this soil.

SOIL ORGANIC MATTER AND SOIL PRODUCTIVITY

The conspicuous role of the soil organic matter, particularly of humus, as a storehouse of nutrients and regulator of their supply to growing plants reveals the importance of this material to the productivity of soil. It is generally true that the soils having a greater content of humus are more productive than soils having less organic matter. It is not true, however, that soils with a relatively small content of humus are necessarily and always less capable of producing a good crop. The inherent productivity of such soils can be surprisingly high, but as a rule it does not last so long as that of soils rich in humus.

It has already been stated that the average content of humus in every mature soil is in equilibrium with the natural environment. Every change of this environment brings about a corresponding change in the content of soil humus. Cultivation of the virgin soil, that is,

the growing of particular selected plants and harvesting of the crops, is one of the most profound modifications of the environment that affect the natural balance of the soil humus. It has been found that in some instances the cultivation and cropping of virgin land caused a rather marked and sharp decrease in the content of organic matter, but that the decline became gradually less and less marked during the years of continued cultivation and finally became negligible. It is apparent that the cultivation created a new environment and that the decline in the humus content of the soil was caused by an adjustment of the soil condition to this new environment.

It does not follow necessarily that all cultivation of the land is accompanied by a decrease of humus in the soil. Many instances are known in which continued cultivation of the soil for many years did not cause any noticeable decline in its content of humus. There are also instances in which cultivation not only did not lower but really increased the content of organic matter in the soil.

Cultivated crops, in many instances, produce a volume of organic matter which is several times that produced by native plants. The residues left in the field after the harvesting of crops, however, may or may not equal the amount of organic matter annually deposited on and in the soil by the native vegetation. If crop residues equal or exceed in volume and quality the residues of the original vegetation, the supplies of humus in the soil will be maintained at or above original levels. If, as has often happened, the volume or quality of crop residues is less than it was for the native vegetation, humus supplies in the soil will decline unless additional organic matter is furnished from other sources.

Regardless of the volume of the crop residues left on the land, harvesting and removal of plants does deprive the soil of certain mineral nutrients supplied by the soil itself. These nutrients originate from the decomposition of minerals in the soils, which is itself a slow process. If the rate of weathering somewhat exceeds the rate of removal by crops, no harmful effects will follow. If, however, the rate of removal by crops exceeds the rate of weathering, the fertility of the soil will be lowered, even though supplies of humus do remain the same. It is probable that declining levels of mineral nutrients in the soil will be associated with declining supplies of humus, in most instances, and that provision must be made both for replacement of the organic matter and replenishment of the nutrient levels if productivity is to be maintained.

It should not be thought that storage of plant nutrients is the one all-important function of humus in the soil. Humus serves a number of functions, all of which are not fully understood at present. The example of the relationship between humus, supplies of mineral nutrients, and the rate of weathering in the soil illustrates the very intimate tie-up between the various components in the soil and emphasizes the fact that maintenance of humus must be an essential part of the entire system man follows in using the soil.

THE SOIL teems with microscopic life—bacteria, fungi, algae, protozoa—as well as being the home of many larger organisms. Each of these has its effect on the soil. The microscopic organisms especially are busy bringing about chemical and physical changes of enormous importance to man's use of the soil. Among other things, they break down complex organic substances into simpler forms; they furnish nitrogen for plant growth. The work, beneficial or harmful, done by each kind of organism is described in this article.

Fauna and Flora of the Soil

By Charles Thom *and* Nathan R. Smith[1]

ROCKS, minerals, and elementary substances on the surface of the earth have been subjected to the corrosive power of the carbon dioxide of respiration and fermentation, to acids produced during the decomposition of successive crops of plant material, and to enzymes secreted by micro-organisms. The soil as we have it today is the cumulative result of ages of such attack, combined with the physical effects of weathering. Few substances added to the soil escape this solvent action. Among examples, metallic sulphur passes over into sulphide and sulphate;[2] iron scatters in several directions; arsenic, selenium, and tellurium in contact with micro-organisms are transformed into vile-smelling gases. The sands of desert areas where the absence of water makes micro-organic life impossible represent soil materials without the presence of life which would transform them into soil. There is no true soil without organic matter, which may be classified as it exists in the soil into living and dead forms.

The organisms vary in size from the microscopic up to the gigantic and in numbers from a few per acre to billions per ounce. They have in reality changed the surface layer of the soil from an aggregate of mineral particles to a mass teeming with organisms and honeycombed by visible channels made by roots of plants or by burrows of animals and insects. There are, also, between the soil particles, invisible channels and spaces of various sizes, intricate networks of microscopic channels whose surfaces are smeared with colloidal slime, and a variable water solution carrying impalpable mineral and organic materials. The most numerous and the smallest of the plants are the bacteria,

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[2] For a review of the literature on this and most of the other subjects mentioned in this article, the reader is referred to Waksman (*446*). Italic numbers in parentheses refer to Literature Cited, p. 1181.

which include forms barely visible under the microscope. The actinomycetes, molds, and algae are each larger but correspondingly less numerous than the preceding one. A similar gradation and correlation in size and abundance occur in the animal kingdom, the protozoa being the smallest and most numerous, followed by nematodes, worms, mites, and insects.

The micro-organisms are not evenly distributed through the pores of the soil. When they are independent of plant roots, bacteria commonly occur in colonies or clumps of a few to many thousands of individuals scattered along the walls of pores or channels in the soil or over the surfaces of soil particles. Molds produce tangled masses (mycelia) of threads (hyphae). Such colonies vary from a delicate network which may envelop one or a few soil granules to great masses of interwoven threads filling certain soil horizons over areas of hundreds of square feet.

THE PROCESS OF DECOMPOSITION

In addition to the micro-organisms that bear definite relation to the pores of the soil and to its mineral or organic constituents, great numbers representing many species are intimately related to the roots of green plants. Such organisms do not travel through soil seeking food but remain in constant association with the surface layers of the roots themselves. When the root hairs and the outer cells of the roots die, their decomposition is accomplished by the attack of these same molds and bacteria, which multiply to great numbers in the process. The ball of earth filled by the roots of a particular plant, with the micro-organisms that accompany them, is the center of very active biochemical activities involving great numbers of micro-organisms even while the plants are living.

The aerial portions of plants under normal conditions are also covered with a varied mixture of micro-organisms. When the plants die, are cut down, or are plowed under, this varied population, already in intimate contact with them, is ready to begin the progressive biochemical processes that carry plant and animal remains toward carbon dioxide, ammonia, and minerals. Plant residues enter the decomposition process carrying sugars, starches, hemicelluloses, celluloses, lignins, proteins, and fatty or waxy substances in percentages specific to their origin. Under favorable temperature and moisture conditions, the micro-organisms present on the material or in the soil quickly increase to fabulous numbers. Easily decomposed substances such as sugars, starches, and proteins disappear first. Celluloses, hemicelluloses, lipoids, and even the lignins are progressively broken down. Lignins, the most resistant, tend to linger, and together with the protein composing the bodies of the microbes they supply up to 75 percent of the dry weight of the final humus or soil organic matter. The humus itself is slowly decomposed into carbon dioxide, water, and simple salts.

There are several methods of counting soil bacteria, none of which gives absolute values. The direct smear and the ratio methods show the dead as well as the living bacteria and are subject to great error. The culture-plate method shows only those that are living and that will grow upon the particular nutrient medium used, which repre-

sents only a portion of the total. Lastly, the dilution method serves fairly well in counting some of the less numerous kinds of bacteria.

Efforts to correlate numbers of live bacteria with soil fertility have usually failed. Food supply, moisture, temperature, physical condition, and reaction of the soil all influence the numbers. The plowing under of green manures or other easily decomposable material will greatly increase the bacteria if other conditions are favorable (*368*). Fantastic numbers, running into billions to the gram, may be obtained by culture from such a decomposing mass (*445*). Similar figures obtained by microscopic methods (direct and ratio types) are reported from ordinary soil and have sometimes been interpreted to mean that only a small percentage of the organisms actually present are capable of developing in culture (*403*). The actual populations are no doubt much greater than the number shown by the plate count but vastly less than that obtained by the microscopic count.

Although particular individual bacteria may survive for long periods under special conditions, the ordinary bacterial generations are commonly very short. The numbers of bacteria present in any situation are continually changed by the death of myriads of organisms and their replacement by others. Billions of dead organisms accumulate in every gram of soil. So enormous is the total that protein ($N \times 6.25$) determined in the usual soil analysis is largely composed of microbic remains.

The most numerous bacteria found in good arable soil are those that are able to use a wide variety of food materials. They break down complex organic substances to simple compounds, carbon dioxide, and ammonia. Certain bacteria initiate the process and others complete it, except where the nature of the material is such as to resist attack.

The majority of soil bacteria are aerobes—that is, they must have air (oxygen) for growth. In many cases, however, very small amounts will suffice. A large group of such bacteria are active in the decomposition of organic matter. Some of them deplete the soil air of oxygen and then obtain a further supply from nitrates if these are present, reducing the nitrates to ammonia or to nitrogen gas. This process (denitrification) occurs especially in waterlogged soil where food is available and free oxygen is scarce. In ordinary field soils there is usually enough oxygen present so that little if any reduction of nitrates occurs.

The great bulk of the decomposition of organic materials in soils is carried on by aerobic organisms. But there are other bacteria, the anaerobes, which will not grow in the presence of oxygen. They occur in all soils but are probably dormant under usual field conditions, becoming important only in certain situations. Their action in breaking down organic matter is relatively slower and less complete than that of the aerobes and leads to an accumulation of ill-smelling compounds. One has only to dig in a peat bog to get the results of this anaerobic type of fermentation. Where the water table is permanently within 4 to 6 inches of the surface, a strong odor of hydrogen sulphide is reached within 10 to 12 inches. Under waterlogged conditions, oxygen is quickly exhausted, and the special type of decomposition releases the hydrogen sulphide. Plant materials

growing at the surface successively die, partially decompose, and gradually sink. By the time they have fallen below the water level, the easily decomposed starches, sugars, and proteins are mostly gone, but the cell-wall materials, celluloses and related carbohydrates, lignin, and other resistant substances, seem to be preserved for ages. The history of bogs has been reconstructed by identifying the species of plants represented by the pollen grains whose walls have resisted decomposition for hundreds of years.

VARIOUS KINDS OF BACTERIA

In the break-down of organic matter, most of the carbon dioxide escapes from the soil into the air. The ammonia, on the other hand, is actively absorbed by the soil, and usually very little is lost. The odor of ammonia normally associated with a decomposing pile of manure or grass clippings disappears when a thin layer of soil is spread over the heap because the soil absorbs the ammonia and at the same time acts as a blanket to keep out oxygen, thus slowing up the rate of decomposition.

Ammonia absorbed by the soil is rapidly changed to nitrite and this to nitrate by nitrifying bacteria, which seem to be most active in the absence of organic matter, particularly in the laboratory, where they are very difficult to grow in pure cultures. Crude cultures of certain nitrite bacteria can be obtained by trickling a mineral solution containing ammonia through a tower filled with broken limestone which has a little soil scattered over the top. The use of a nitrite solution instead of ammonia will give a good development of the nitrate bacteria.

There are a number of forms of free-living bacteria that can fix nitrogen, several of which are widely distributed. Of these, Beijerinck described *Azotobacter* from soil in 1901 as a genus of micro-organisms that can use the nitrogen of the air in building up proteins within their bodies and thus by continued growth and death can increase the nitrogen content of the soil. This fixation of nitrogen can take place only in a neutral or alkaline soil. Acidity (pH values less than 6.0) apparently paralyzes the mechanism of nitrogen fixation. The bacteria can, however, remain alive in a soil more acid than pH 6.0, even though they fix no nitrogen.

Azotobacter has been found in certain soils all over the world, but in relatively small numbers varying from a few hundred to a few thousand per gram of soil. There is some question as to the importance of this bacterium to soil fertility because of the small numbers. Up to 40 pounds increase in nitrogen per acre per year has been attributed to *Azotobacter* by some workers, but others have become skeptical of its ability to give these results under field conditions. In the laboratory, in the presence of plenty of carbohydrate and the absence of much nitrogen, it is very easy to obtain an increase in the nitrogen content of cultures that contain billions of organisms. Further investigations will be necessary before the discrepancies between the laboratory results and the small numbers in the field can be interpreted.

Nevertheless the importance given to *Azotobacter* in the literature has led to the proposal to use it for determining the fertilizer needs of soil by the use of soil plaques. Unfortunately, the successes of this

method are restricted to special soils and conditions and hence it has no general application. Other micro-organisms, especially *Aspergillus niger* and *Cunninghamella,* have been proposed for similar determinations. When properly calibrated against field or greenhouse tests, they may be used to compare the fertilizer needs of particular fields of related soil types.

Early Roman observers recognized the value to the soil of growing legumes and exhorted the farmers to plant more of them. But it was not until 1886 that the reason for the beneficial effect of legumes was discovered. Since then the literature on this subject has become so extensive that a whole volume is needed to cover it adequately (*116*).

Briefly, the beneficial effect of legumes is due to the nodules on their roots. These are caused by bacteria that penetrate the rootlets and stimulate the plant to produce a growth at that point. The bacteria grow and reproduce inside this nodule, getting their carbohydrate and mineral food from the plant and their nitrogen from the air to form proteins that are released to the plant. Legumes, therefore, are able to grow normally in soil poor in nitrogen, provided other conditions such as soil reaction and available minerals are favorable.

The nodule organisms themselves have been found to belong to several groups, each of which is capable of producing nodules upon a series of leguminous plants. Within these groups there now appear to be special strains of nodule organisms peculiarly efficient upon particular legumes. The proper artificial culture can be grown in the laboratory and applied to the seed at planting time. By this means inoculation by efficient bacteria is assured, whereas if the inoculation is left to nature the rootlets might be invaded by a less efficient organism.

The amount of nitrogen fixed by legumes and added to the soil if they are plowed under varies greatly, depending upon the plant, the mineral and nitrogen content and reaction of the soil, and the season. Fifty to one hundred and fifty pounds of nitrogen per acre per year are fixed under average conditions. Under special conditions even greater gains may be obtained.

ACTINOMYCETES

As compared with that of the bacteria, not much is known of the physiology of the actinomycetes in soil. They are next to the bacteria in numbers, ranging from hundreds of thousands to a few millions per gram of soil. In size they are not much larger than the average bacterium. Many of them resemble molds in their manner of growth and in physiology. They are able to grow in drier situations and in deeper layers of the soil and they require less nitrogen than the bacteria. In field soils, they are most abundant in old sod and hence are probably associated with the decomposition of the grass roots. Great numbers may also occur in compost piles.

As a rule actinomycetes may be said to be decomposers of organic matter, attacking the celluloses and perhaps the more resistant soil humus. In this capacity they are important from the fertility standpoint in that they may set bound nitrogen free as ammonia. While certain species are pathogenic (that is, attack living plants and animals, producing disease), most of them are saprophytic (feed on dead material).

FUNGI

Associated with bacteria and actinomycetes in the rotting of plant remains are the fungi. Some of them are parasitic and begin the task of disintegration while plants are still growing; others attack dead plants only. Both are carried down with dead vegetation upon the surface of the soil or follow the root systems in its upper strata. Still others carry on their whole vegetative lives below the surface and only come to the surface to set free their spores. These species dot the meadows and pastures with mushrooms and puffballs and crowd the forest floor with varicolored fleshy bodies of *Boletus*, *Collybia*, *Tricholoma*, *Russula*, *Lactarius*, *Amanita*, the fantastic coral fungus (*Clavaria*), the slime molds, the cup fungi in their multitude of forms, and those microscopic molds whose beauty escapes detection until it is revealed by the compound microscope or studied in cultures.

Among these molds are many curious forms especially adapted to restricted conditions, but more important by far are cosmopolitan genera present in soils everywhere and participating in the decomposition of organic material. Common examples of these are species of *Alternaria*, *Cladosporium*, *Mucor*, *Rhizopus*, *Zygorrhynchus*, *Penicillium*, *Aspergillus*, and *Trichoderma*. Everywhere dark-walled forms, species of *Cladosporium*, *Alternaria*, *Helminthosporium*, and similar genera cover the surfaces of vegetation in the fall and winter after the first frost and give it the gray, dirty, or weathered look so familiar in the garden and fence corner.

Among such fungi many species are harmless saprophytes; others are able to attack roots of crop plants as well as to live independently in the soil; still others are parasites that cannot live in the absence of host plants. Under natural conditions of competition the effects of the destructive types are only occasionally seen. Under cultivation, however, the conditions of growth found in nature are disturbed, and native or introduced species of fungi frequently become epidemic. In certain regions of the Southwest, the root disease caused by *Phymatotrichum*, a native fungus, has become enormously destructive. While the greatest damage has been done in the cottonfield, shade trees, vegetables, and ornamentals are not spared. Similarly, wilt diseases affect cotton, flax, watermelon, and many other cultivated crops. The fungi involved are forms that take advantage of the new conditions and multiply until sometimes whole areas are so badly infected that crop production is no longer profitable.

MYCORRHIZA

Close association of fungi with the roots of green plants occurs conspicuously in the forest. The feeding rootlets of the forest trees turn upward from main roots and penetrate the surface layers of soil and decaying litter as a fine network. In such situations the ultimate tips or the annual series of feeding rootlets of many species are covered with mantles, or closely woven masses of mold hyphae. In other species the mold threads penetrate between the cells of the outer layers of the root cortex. This association appears to serve as one means of breaking down plant food by fungous action so that it can be absorbed directly by the plant. Such mycorrhiza takes many forms and occurs on annual

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plants as well as on trees. The fact that such relations occur and that both organisms have adjusted themselves to a sort of communal life is well established, although the extent of interdependence between fungus and green plant is a matter of controversy.

PROTOZOA AND MYXOMYCETES

In this population of millions of organisms to the gram, the one-celled animals, protozoa, constantly appear, primarily as destroyers that prey on bacteria. They are mostly free swimming and are dependent upon free water for activity. Certain of the smaller species have been found to be represented in soils of widely differing physical and chemical composition and under most varied climatic conditions (*336*). The larger ciliated forms are only found under excessively wet conditions in highly fertilized soil or in loose-textured swamp areas.

On account of their activity in feeding upon other organisms, the protozoa have been regarded as a factor in maintaining microbiological balances. Bacterial populations seem to be reduced by them in some soils but are not affected in others.

The slime molds form a group of micro-organisms that has been often overlooked. These myxomycetes seem to be intermediate in their characteristics between the protozoa and the fungi. They flood the surface layers of moist soil rich in organic matter with colonies of individuals that prey upon the smaller forms, such as bacteria, actinomycetes, and molds. After their feeding season is finished they come together in great aggregates of individuals or fuse into jellylike masses that ultimately come to the surface and produce their spores in variously formed, often very beautiful structures.

They too are considered significant as a factor in maintaining a balance in soil population.

WORMS AND BURROWING ANIMALS

Worms varying in size from great earthworms to forms scarcely visible to the naked eye are represented in the fauna of most soils. The smaller forms are seen mostly near the surface in the A horizon. The well-known earthworms feed at or near the surface upon plant remains, which are ingested or dragged into their burrows. These species are so dependent upon moisture, however, that they must encyst or withdraw into the deeper layers of the soil in dry weather to keep their bodies moist. Since they drown in water, the larger species are found inhabiting permanent burrows, often running vertically several feet, which make possible a safe balance between air and moisture requirements. Large amounts of earth are ingested with their food and pass through their alimentary canals. Their casts, which consist of earthy matter bound together with the humidified residues of food eaten, furnish a suitable environment for many micro-organisms. Marbut expressed the belief that in certain areas the granular condition characterizing whole layers of soil was due to earthworm casts. Certain mulls, or granular mixtures of mineral and organic material produced by earthworms, give particular areas of the forest floor their whole character.

The larger animals that burrow into the earth for protection or in search of food play a secondary part. Their holes or burrows form

open channels which carry air and rain water into the deeper layers, increasing the absorbing power of the soil. Where they form complex networks, such as may be readily observed in the forest or in grasslands, these burrows are capable of impounding great quantities of rain water which might otherwise run away. Sometimes they also form the starting point where streams of water begin the break-down of banks and hillsides, resulting in the ruin of large areas of soil.

BALANCED MICROBIAL POPULATIONS

In virgin soil or in areas in which natural competition has been undisturbed for long periods, the micro-organisms and green plants are found to reach a fairly stable balance. The swamp, the forest, the prairie, change their aspects slowly over long periods. When farming operations are introduced, this balance is destroyed. Whole sections of the organic population are wiped out, and new alignments are started. Plowing and cultivating increase the activities of the micro-organisms, and the accumulated organic remains that made the freshly broken prairie so fertile are broken down at a greatly accelerated rate. In many areas no adequate steps have been taken to replace what has been destroyed. Micro-organic activities in the soil are desirable when they serve man's purpose; they become undesirable when they are stimulated to the point where they destroy fertility faster than it can be replaced.

Studies of the microbial population of the soil have thus far been mainly descriptive—totals have been enumerated; particular species have been isolated and studied in the laboratory; specific treatments have been applied; and effects upon total organisms have been determined. Constructive experimentation is required to determine just what microbial activities are needed for particular crops in each soil group and how those activities may be maintained at desirable levels.

Correspondingly, the existence of unfavorable microbial activities in many soils is already known. Much experimentation will be necessary to establish means of elimination, of control, or of replacement of undesirable by desirable species.

IN THE *beginning there is parent rock, inert and dead. What kinds of rock are there? How are they turned into the parent material of soil and this into soil itself? In soil formation what part is played by climate, by living organisms, by the slope or relief of the land, by rains and rivers and wind and ice, and by time itself? This article discusses these questions. A somewhat more technical section at the end deals with the differences that characterize the various groups of soils.*

Formation of Soil

By H. G. Byers, Charles E. Kellogg, M. S. Anderson, *and* James Thorp [1]

SOILS are natural media for the growth of plants. They are mixtures of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, and air, in greatly varying proportions, and have more or less distinct layers or horizons developed under the influence of climate and living organisms. The cross section of horizons from the surface to the parent material is known as the soil profile. The degree of profile development is dependent on the intensity of the activity of the different soil-forming factors, on the length of time they have been active, and on the nature of the materials from which the soils have developed. Soils are dynamic in character—they are constantly undergoing change—but they normally reach a state of near equilibrium with their environment, after a long period of exposure to a given set of conditions, and they may change but little during periods of hundreds or even thousands of years unless there is a change in the environment.

THE FACTORS OF SOIL GENESIS

True soil is the product of the action of climate and living organisms upon the parent material, as conditioned by the local relief. The length of time during which these forces are operative is of great importance in determining the character of the ultimate product. Drainage conditions are also important and are controlled by local relief, by the nature of the parent material or underlying rock strata, or by the amount of precipitation in relation to rate of percolation and

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run-off of water. There are, therefore, five principal factors of soil formation: (1) Parent material; (2) climate; (3) biological activity (living organisms); (4) relief; and (5) time. These soil-forming factors are interdependent, each modifying the effectiveness of the others. Thus, the character of the relief influences, through drainage and run-off, the effects of rainfall and of time. The character of the parent material modifies the effects of rainfall and relief of a given area. The character of the vegetation is, in part, determined by temperature and rainfall and in turn modifies the effects of these, particularly of rainfall. Despite these complex interrelationships, it is possible to gain a helpful insight into the question of soil formation by consideration of each of the formative factors separately.

FORMATION OF PARENT MATERIAL

The first step in the development of soil is the formation of parent material, accumulated largely through rock weathering. The parent rock is a relatively inert storehouse of future soil material rather than an active factor in soil formation. The distinguishing characteristics of the soils of the great soil groups are primarily due to the effects of climate and biological action on rocks, but many of their subdivisions owe their distinctive characteristics to parent material.

Rocks [2]

Broadly speaking, rocks include both consolidated (hard) and unconsolidated (soft) mineral and organic deposits of the earth. The mineral rocks furnish by far the greater bulk of material for most soils, but the ultimate product contains important amounts of water, oxygen, and carbon dioxide in chemical combination contributed from other sources. The rocks of the earth are of three principal kinds: (1) Igneous or primary rocks; (2) sedimentary, eolian, and glacial rocks; and (3) metamorphic rocks.

Igneous Rocks

Igneous rocks are formed by the hardening of various kinds of lavas and are composed of different minerals in various proportions. Coarsely crystalline texture is promoted when lavas cool very slowly—usually at great depths below the earth's surface. Finely crystalline and glassy textures develop when lavas are quickly cooled by being intruded between layers or in joints of other rocks or by flowing out over the land surface.

Igneous rocks not only vary in the size of crystals of component minerals, they also vary considerably in chemical character. Some of them are composed almost entirely of quartz, which is distinctly acidic in character, while others contain a high proportion of iron, calcium, magnesium, and other basic elements and are known as basic rocks. Between these two extremes there are a large number of both coarse-grained and fine-grained igneous rocks with varying proportions of acidic and basic elements. The rhyolite-granite group includes rocks dominantly composed of quartz and feldspar with minor quantities of other minerals. The coarse-grained members of

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[2] For more details concerning rocks see Clarke (*65*).[3]
[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

the group are called pegmatite granites and the finely grained members rhyolites; the glassy members are known as obsidians.

Rocks high in feldspar and iron-magnesium minerals include the coarse-grained syenites and the fine-grained trachytes. Rocks high in feldspars, feldspathoid minerals (similar in chemical composition to the feldspars), and iron-magnesium minerals are known as nepheline-syenites and phonolites. The latter are dark-colored, very dense and fine-grained, and give a ringing sound when struck with a hammer. Other coarse-grained igneous rocks are quartz monzonite, quartz diorite, gabbro, and several others of less importance. Fine-grained rocks include latite, dacite, andesite, and the basalts. The dark-gray andesites and nearly black basalts are especially important sources of soil material. Basalts contain a higher proportion of basic minerals than andesites.

Another important class of igneous rocks comes from volcanoes. Fragments of volcanic materials are blown from craters and spread over the surface of the land or water by winds. Volcanic ash is usually a soft mass of very finely divided glassy or finely crystalline particles. The composition varies as widely as the composition of other igneous rocks, and to a certain extent the fertility of the final soil may reflect this variation in composition. In Puerto Rico and parts of western United States, many volcanic-ash deposits have been stratified by water. Because of their finely divided condition and porous consistence, most volcanic ejecta are easily weathered into soil material.

Sedimentary, Eolian, and Glacial Rocks

Sedimentary rocks are either consolidated (hardened) or unconsolidated fragmentary rock materials deposited by water. They vary in texture from gravelly or stony to the finest clays. The more usually recognized sedimentary rocks are pudding stone or conglomerate, composed of gravels and coarse sands; sandstones, composed of sands of greatly varying composition; clays and shales; and limestones with varying proportions of impurities. In addition to these there are other sedimentary rocks of greatly varying texture which might be called loam stones or silt stones, according to their particle-size composition. Conglomerates and sandstones may be made up almost entirely of quartz, or they may contain a high proportion of such minerals as feldspars, hornblende, pyroxine, and glauconite. Sandstones composed of quartz and feldspar and minor amounts of other minerals are known as arkose, and their chemical composition is similar to that of granite and gneiss. Glauconite, or greensand, is rich in potash, silica, and alumina and easily weathers down to a clayey mass. Soils developed from quartz sandstones are likely to be infertile, whereas those from sandstones containing a goodly proportion of other minerals are more likely to be fertile, although it will be seen from what follows that it is possible for a very poor soil to develop from material rich in plant nutrients. Some sandstones and conglomerates are cemented by silica and weather very slowly, while those cemented by lime ($CaCO_3$) weather rapidly. When iron hydroxide is the cement for sandstones and conglomerates the product is known as ironstone. Many sandstones, conglomerates, and loam

stones, such as recent alluvial and lake deposits, are unconsolidated or only weakly cemented.

Clays and shales vary exceedingly in composition. Some of them are highly calcareous, while others contain no lime; some have a high percentage of very finely divided mica, while others contain none; some are composed of finely ground rock flour in which the chemical composition of the original rocks has been changed but little, and others are composed of highly weathered materials. Some clays and shales contain high percentages of silica while others have little or none. All of these factors have a bearing on the ultimate productivity of the soil. For example, productive soils are more likely to develop from highly calcareous clays than from those containing no lime, and from clays with a high percentage of rock flour than from those that have been very strongly weathered over a long period of time. High-silica clays usually have a greater capacity for holding plant nutrients than those of relatively low silica content.

Many productive soils are developed from limestones, some of which are very hard and are composed almost entirely of calcium carbonate or of mixtures of calcium carbonate and magnesium carbonate (dolomitic limestones). Others are soft and chalky and contain a high percentage of clay or sand. These impure limestones merge into the calcareous sandstones and shales or clays. In nature these sedimentary rocks frequently occur in alternate beds varying from thin plates to deep strata several feet in thickness. Frequently siliceous material, such as flint or chert, may be deposited within the limestone. In some places these are a result of deposition from solution in other rocks as well as limestone. Since chert and flint are very hard and resistant to weathering, soils developed from limestone containing them may be very stony. The noncalcareous impurities of limestone usually form the bulk of the material from which soil is formed after the lime has been dissolved.

Eolian (wind) deposits are unconsolidated rocks which are very important soil materials. These consist almost entirely of loess and sands. Loess is composed of accumulations of dusts. It is common near the edges of present or former deserts and along some alluvial flood plains; in some instances deposits reach a thickness of as much as 300 feet. Since the mineralogical composition is extremely complex and variable, there is an abundance of mineral plant nutrients in most loess deposits, including more or less free carbonate of lime. Deposits are usually uniform in texture and color and stand vertically in cliffs where eroded.

Sand dunes are common in many regions, especially along sea and lake shores and within or near the margins of deserts. They may be composed largely of quartz or of fragments of many different minerals. They are not an important source of material for soil formation, but in some places they migrate over the land and destroy crops and even forests. Migrating dunes are common around the southern end and eastern shore of Lake Michgan and in the desert areas of southwestern United States.

Many glacial deposits resemble unconsolidated conglomerates. Some of them are composed of mixed and unstratified gravels, boulders, sands, and clays, while others have been reworked and stratified by

water. Some of the most important soil types of northern United States are developed from these materials. The glaciated portion of the United States extends as far south as the Ohio and Missouri Rivers and from the northern Atlantic seaboard to east-central Montana. In addition there are a few isolated areas of less importance in the mountains and valleys of northwestern United States and in Alaska.

Much of the glacial drift is composed of fragments of many different kinds of rocks, and for this reason it nearly always contains fair to plentiful reserves of mineral plant nutrients. In some places, however, such as on the high plateaus of southern New York, it is composed dominantly of rock materials low in the minerals necessary for plant growth. In general the most productive soils in glaciated regions develop from glacial drifts containing a considerable portion of limestone. This is especially true of the soils developed under the forest in the humid regions. Some very poor soils are developed from glacial drift composed largely of noncalcareous sandstone and shale.

Peat is a peculiar type of sedimentary material and ordinarily is considered to be a rock only in a broad sense. Peat is the parent material of organic soils, such as various kinds of muck and peat soils (Bog and Half Bog soils). Some peats are composed largely of woody fragments, some of reed and grass remains, some of sphagnum (peat moss), and some are essentially jellylike or colloidal (very finely divided) materials derived from these plant remains. Many peats are extremely acid in reaction and very low in mineral plant nutrients, although some contain a relatively high percentage of lime where they have been watered by seepage from limestone rocks or calcareous drift.

More soluble sedimentary rocks, such as various kinds of soluble salts, gypsum ($CaSO_4$), and sulphur, are fairly common recent deposits in arid regions, and outcrops of such rocks also occur in some of the older geological formations of humid regions. They may modify the character of soil material but rarely make up the bulk of it.

Metamorphic Rocks

When igenous and sedimentary rocks are exposed to intense heat or to very high pressure, or both, their structure and mineralogical composition are considerably changed. The process is known as metamorphism, and the products are known as metamorphic rocks. Among the most common of the metamorphic rocks are gneiss, quartzite, schist, talc and serpentine, slate, phyllite, and marble. Gneiss is a coarse-grained banded crystalline rock usually derived from igneous rocks of various kinds, although some gneisses are formed through the metamorphism of conglomerates or arkosic sandstones. Gneisses are described as granitic, syenitic, dioritic, etc., according to the minerals of which they are composed and their resemblance to various igneous rocks. Soils derived from them are likely to have properties similar to those derived from the original igneous rock.

Quartzite is formed by the metamorphism of quartz sandstone or conglomerate and is composed almost entirely of quartz. This rock weathers very slowly, and most soils developed from it are unproductive no matter what the climatic conditions.

Schist is the metamorphic product of several kinds of rocks, both igneous and sedimentary, and is commonly derived from sandy clays

and shales, through a high degree of metamorphism. Talc, serpentine, and soapstone are metamorphic products of the weathering of siliceous magnesian rocks. Slates and phyllites exhibit a high degree of cleavage and break into thin plates; the former are hard and often dark-colored, while the latter are somewhat softer and contain a high percentage of very finely divided mica or chlorite. Chemical weathering is much slower than physical weathering on them. Clays commonly become hardened into shales. Under heat and pressure shales are changed to slate, phyllite, or mica schist, depending on the intensity of the metamorphism and the composition of the original clay.

Marble is the metamorphic equivalent of limestone. It may be composed either of relatively pure calcite (lime), or it may be dolomitic. Marble includes many impurities corresponding to the orginal impurities in the limestone rock.

Relation of Rocks to Soils

The character of the ultimate soil product derived from any given rock will depend in a large degree on the activity of the other factors of soil formation. A rock may be rich in the minerals essential to plant growth and still produce an exceedingly poor soil. On the other hand, under suitable conditions of climate and vegetation, fairly productive soils may be produced from weathered rocks relatively poor in plant nutrients. Within any local region having only minor differences in climate and vegetation, the kind of parent rock has an important bearing on the ultimate nature and usefulness of the soil. For example weathered gneisses and schists of the Piedmont Plateau of eastern Pennsylvania are the parent materials of very excellent soils for general farming, known as Chester and Manor series.[4] In the same region soils derived from weathered serpentine are unproductive for agricultural crops. The highly productive Sassafras loam has developed from the mixed clays, silts, and gravels of the Coastal Plain of New Jersey, while the Lakewood sand, which is almost useless for crop production, has developed from the quartz sands of the same region.

Primary Physical Weathering of Rocks

Primary physical weathering consists in the loosening and breaking up of the rocks. Joint planes and lines of stratification are the first lines of attack in this process. Daily and seasonal variations in temperature cause expansion and contraction of rocks, and, since the component minerals have different rates of expansion, tension is set up within the mass, and the rock gradually crumbles. Variations in temperature are especially active when rapid and when they pass across the freezing point. This effect is especially important in coarse-grained rocks such as granite.

Exfoliation

Where rocks are exposed at the surface they are subject to almost daily rapid heating and cooling, especially in temperate regions. Since most rocks are poor conductors of heat, the sun warms the outside

[4] In many places in this discussion it seems desirable to make reference to actual soil series or types in the United States by way of illustration. Their location is shown on the soil map at the end of the volume, and their descriptions are given in part 5, Soils of the United States, p. 1019.

shell of rock much more rapidly than the interior, and expansion is correspondingly greater. At night the surface cools and contracts very quickly. The rapid expansion and contraction corresponding to daily changes in temperature ultimately cause rock fragments to peel off in flakes or leaves—a process known as exfoliation. Exfoliation is effective on all dense-structured rocks. Dark-colored, fine-grained igneous rocks, such as basalt, are exfoliated very readily, and the leaflike fragments tend to hold their shape longer than those split off from the coarser-grained igneous rocks. The latter soon crumble into gravelly fragments.

FIGURE 1.—Concentric weathering of fine-grained igneous rocks, characteristic of tropical regions. Near Kilauea, island of Kauai, Hawaii.

Exfoliation is accomplished to an important degree as a result of chemical weathering, especially in warm and humid regions. For example, granitic and fine-grained igneous rocks of the Tropics and sub-Tropics are broken apart piecemeal by the hydrolytic action of water on clay-forming minerals. Water, with some carbon dioxide in solution, finds its way into the joint planes of the rocks and thence into cleavage planes of clay-forming minerals, such as feldspars. Where water comes in contact with these minerals, chemical changes occur (hydrolysis and carbonation), and clays and carbonates, which have a larger volume than the original minerals, form along the contact planes. The formation of these compounds causes expansion, slight in extent but resistless in strength, which breaks up the original rock into fragments and further exposes the unweathered portions to the agents of chemical weathering. In this manner coarse-grained rocks are rapidly reduced to gritty fragments. Fine-grained rocks are more slowly reduced and eventually take the form of concentric rings of weathered, crusty material surrounding a rounded core of fresh rock (fig. 1). In this case chemical weathering nearly keeps pace with disintegration.

In warm-temperate and tropical regions this process is probably more important and significant than the disintegration brought about by expansion and contraction of rocks with temperature changes in cooler regions or by the resistless expansion of ice in the cracks and crevices of rocks in colder regions. In fact, the hydrolytic action of water is an important contributing cause to the comminution (reduction to fine fragments) of rocks and minerals in the temperate zone, both in humid and arid regions.

Ice and Root Wedging

In cool-temperate regions water fills crevices during the warm season and is frozen during colder periods. The resulting expansion, characteristic of ice formation, breaks the rocks into fragments. This process is especially important during late autumn and late winter, when there is much freezing and thawing.

Rocks are also broken apart by the expansion of roots in cracks. Tree roots work their way down from the surface along joint planes and stratification lines and wedge the rocks apart. Smaller roots gain entrance to minute crevices between mineral grains or in the cleavage planes of individual minerals and also help to break up the rocks.

Secondary Physical Weathering

Grinding by Rivers and Ice

The fragments made by primary methods of physical weathering are further broken up by secondary processes. Creeks and rivers collect rock fragments, roll them along their beds, and grind them into finer particles. Deposits of sand and silt in the bends and on the banks of almost any stream bear witness to the importance of this process. The rate of grinding depends very largely on the amount of material suspended in the water and the speed of the stream. The carrying power of water varies approximately with the sixth power of the speed—that is to say, if the speed of the current doubles, the carrying capacity is increased 64 times. The greater the carrying power, the more important the grinding effect along the bottom of the stream. Waves of seas and lakes produce a grinding action among the fragments along the shores.

Materials collected and ground into fine fragments by streams are deposited on flood plains and deltas and, with intermixed materials washed from hillsides of interior regions, go to make up some of the most important soils of the world. The Mississippi flood plain and Delta and the flood plains and deltas of other large rivers of the United States, as well as those of the Yellow and Yangtze Rivers of China, of the Ganges River of India, and of the Amazon of South America, are excellent examples. A very large proportion of the world's population gains its living from the cultivation of alluvial soils. The productivity of alluvial soils has a more direct relationship to the kind of rocks from which the materials were derived than that of most soils, because they are young and only slightly developed and are receiving continual additions of new material. If materials are washed from rocks of low mineral plant nutrient content or from poor soils, they are

likely to be poor and unproductive; but large rivers draw their soil materials from such a wide range of rocks and soils that their deposits are likely to make productive agricultural soils.

Glaciers—rivers and seas of moving ice—collect loose rock fragments and not only grind them together to form smaller fragments but also use them as tools for gouging out still more fresh rock from beneath. The grinding effect is especially evident in regions where glaciers are now active. For example, glacial ice on the mountains of northwestern United States flows slowly down into the valleys, where it melts away. Ground rock fragments as fine as flour give the water a milky tint as it flows away from the glacier front, and the rushing streams push innumerable boulders and gravels along their beds away from the glacier. At the present time there are continental glaciers only in Greenland and Antarctica, where they are actively plucking and grinding stones from the rock masses beneath them. During the geologically recent glacial period (Pleistocene) of North America and Europe, however, continental glaciers covered most of Canada, part of northern United States, and much of northern Europe.[5]

It is estimated that these sheets of ice in many places exceeded a mile in thickness. They transported and pulverized an enormous quantity of rock material and deposited it over a very large area. The richest agricultural regions of north-central United States are underlain by materials deposited by these ancient glaciers or by rivers which flowed from their fronts. The glacial invasions of northern United States came from centers in Canada from which most of the unconsolidated material was removed. At the present time large expanses of territory in Canada have very thin soils, because the glaciers scraped the rocks bare and pushed and carried the materials to southern Canada and northern United States. Most of the soils from the Ohio and Missouri Rivers northward to the Canadian border are derived from rock materials deposited by the glaciers or by glacial streams and lakes.

Wind Scouring, Landslides, and Avalanches

In desert and semiarid regions, where vegetation is sparse and winds of high velocity are more or less prevalent, much physical weathering is accomplished by the scouring action of wind-blown sand, which cuts fragments of stone from outcropping rocks of the region. Fragments thus produced are blown into adjacent regions to produce sand dunes and loess.

Some physical weathering is accomplished by means of landslides, avalanches, and soil-flowing (solifluction), especially in hilly and mountainous regions. Landslides and avalanches accomplish much work in steep mountainous regions, as in central Puerto Rico; but they are also fairly common in hilly lands where parent rocks are largely shales and clays, as in northern Wyoming and southeastern Ohio. Freezing and thawing and seepage of water on slopes aid in the process.

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[5] Various estimates indicate that the first part of the glacial period began more than 1,000,000 years ago, and after several advances and retreats of the ice, the last remnants melted away a few tens of thousands of years ago.

Chemical Weathering

Hydrolysis and Solution

Hydrolysis is the predominating process by which the chemical weathering of rocks takes place. Technically speaking, simple solution probably is the first reaction that takes place between water and any kind of rock, but the progress of this action is, in the case of most silicate minerals, infinitesimal when considered independent of hydrolysis. The hydrolysis and solution of most kinds of rocks are hastened by the influence of carbonic acid and various more complex organic acids. Such products are carried out in the ground water. The more finely divided the rock fragments, the more rapid is the action of water so long as it is able to filter through. Among the materials most readily removed in solution are compounds of potassium, sodium, calcium, and magnesium, as well as a certain amount of silicic acid. Solution is especially important on the more soluble rocks such as gypsum, limestone, and rocks containing calcareous cement. Soils can be formed from limestones only when a certain amount of impurities has collected following the removal of calcium carbonate from the rock.

At all stages of the process of breaking up of large masses of rocks into finer material, water is reacting with the minerals, forming secondary products. This is the process called hydrolysis, and it is essentially the exchange of component parts between the minerals and water. For example, when water comes in contact with a simple mineral such as calcium silicate ($CaSiO_3$) some of the mineral dissolves, and the water reacts with the silicate to produce some calcium hydroxide and silicic acid ($CaSiO_3 + 2H_2O \leftrightarrows Ca(OH)_2 + H_2SiO_3$). It will be seen that a change of this sort involves an exchange between constituent parts of the mineral and component parts of the water, resulting in the formation of two substances having properties different from the original mineral and water.[6] Clays are, for the most part, mixtures of complex silicates. They contain varying proportions of alumina, iron oxide, and silica. Some clays are very high in silica, while others consist almost entirely of the hydroxides of iron and aluminum, the silica having been almost entirely removed in solution.

The chemical composition of clay influences to a considerable degree the amount of water held as a part of its constitution. Clays with a high content of iron oxide and alumina usually contain considerably more water than clays relatively low in those constituents and high in silicia. This is not to be confused with the more loosely held water described in another article as hygroscopic water (Water Relations of Soils, p. 897). When water is taken up or is lost in any manner, stresses and strains tend to be set up in the rocks, and this assists physical weathering.

Hydrous oxides of iron and aluminum are each subject to dehydration in varying degrees under different conditions. Such compounds in different stages of dehydration normally occur in certain soils.

[6] More complex phases of hydrolysis, by which various kinds of clays are formed, are discussed in General Chemistry of the Soil, p. 911.

Limonite, geothite, and perhaps the completely dehydrated form, hematite, are found and are usually mixed with a similar group of the hydrous oxides of aluminum. The tendency toward dehydration is particularly marked in some of the tropical regions where highly lateritic soils are formed.

Carbonation (Carbonatization)

In the reaction cited above, the readily soluble calcium hydroxide is easily washed away, but it may react further with the carbon dioxide of the air or of the soil water. In this case, calcium carbonate will be formed, and it will either accumulate in the soil or be washed away according to whether or not there is sufficient water in circulation. In a similar manner carbonates of magnesium and other metals are formed in the soil material or in the soil itself. Carbonation is most rapid in regions of high rainfall, but the products of carbonation are removed so rapidly in such areas that the soil will actually contain fewer carbonates than that developed in semiarid regions.

Oxidation and Reduction

Changes in the state of oxidation of some of the elements, particularly of iron and manganese, take place under certain soil conditions. Mineral powders exposed to moderately dry air undergo little or no change. When they are enveloped by water, however, hydrolysis converts some of the ferrous iron and manganous form of manganese into a solution in the form of slightly soluble hydroxides, among which the iron, ordinarily, greatly predominates. These compounds are capable of taking up oxygen from the air to form more highly oxidized compounds of extremely low solubilities. Such oxidation is often evident from the formation of scums or crusts which have the characteristic color of iron rust and consist primarily of ferric hydroxide, more or lesss dehydrated.

Under certain soil conditions a reverse action takes place. The mere absence of air is not sufficient to cause these compounds to lose oxygen. However, certain organisms associated with the decomposition of organic matter are capable of extracting oxygen from such compounds as ferric hydroxide when air is excluded by water. This change produces an iron compound of greater solubility. When soils are waterlogged for a considerable period significant proportions of the iron may be reduced. These oxidation and reduction changes may play an important role in soil-profile development and in the formation of parent material from rocks.

EFFECTS OF PARENT MATERIAL ON SOILS

Soil material is the product of physical and chemical weathering of rocks and minerals. Since unconsolidated rocks such as sands and clays are nearly always more or less weathered chemically, they may serve as parent materials of soils without having to go through further physical and chemical changes. Soils form directly from them. Parent material may be shallow or deep. It may consist of fragments of widely varying sizes or be of uniform texture; of coarse rock fragments with smaller quantities of finer materials, or the

converse; it may consist essentially of a single mineral such as quartz or feldspar or of fragments of many kinds of minerals or of rocks of varying mineralogical composition. The finer materials may be in almost any stage of hydrolysis and leaching with high silica and low alumina content or the reverse. Parent material may be exceedingly resistant to change or may be subject to rapid alteration under the prevailing environment.

Over a long period the general effect of soil-forming processes is to obliterate the differentiating influence of parent material. Many soils may be examined from the surface to a depth of 2 or 3 feet without finding any inkling as to the nature of the parent rock from which the soil material was derived. So-called normal parent materials are mixtures of clays and unweathered minerals and rock fragments of considerably varying composition. These develop into soils the characteristics of which depend almost entirely on the factors of biological activity, relief, climate, and time.

If parent materials are devoid, or nearly so, of mineral plant nutrients it is safe to assume that it will be impossible for fertile soils to develop from them. However, materials of this type are not usual.

Direct Effects

Parent materials have a strong modifying effect in many places on the type of soils developed and more especially on the rate at which development takes place. For instance, quartz and arkose sands are much more subject to the dissolving effect of water than materials high in clays. This is because water passes easily through the materials and there is a smaller proportion of basic elements to be dissolved away. If lime cement is present in these sandy materials or if the rock contains large quantities of lime, removal by solution is very much delayed, but it is not necessarily prevented.

Such rocks as shales, slates, silt stones, phyllites, or mixtures of two or more of them may have the effect of checking internal drainage. This is especially true if the materials have been mixed and compacted by glacial action. For example, imperfectly and poorly drained soils are very common on relatively steep hillsides in New York and New England, because the compact shaly and slaty materials prevent the downward movement of water through the soil. Soils of the Volusia, Erie, and Culvers series are good examples. In most places these occur on gentle to steep slopes, the soils of which would normally be well drained.

In the semiarid and arid regions, parent-material clays sometimes become saturated with sodium and are often very impervious to water. These conditions favor the development of soils belonging to the Solonetz and Soloth groups.[7]

Heavy, waxy clays, whether calcareous or not, are very resistant to soil-forming processes and may retain their essential parent-material nature throughout long periods. Sandy soils develop from very sandy parent materials quite regardless of the other conditions.

[7] References to the names of the great soil groups can scarcely be avoided in this discussion. Their particular morphology and evolution are dealt with later in this article.

Residual Effects

Parent materials in many places have an important residual effect—so-called because it resides or remains in the soil for a long time—on the soil, especially in regard to its productivity for trees, grasses, or crops. Such residual effects are extremely difficult to determine by merely examining a soil in the field without regard to what is growing on it. By examining the parent material carefully, however, or even the parent rock beneath, one can frequently get indications as to what to expect from the soil. For example, in humid regions a soil more productive of the common agricultural crops and grasses may be expected from glacial till containing fragments of limestone than from materials derived entirely from acid shales and sandstones. Forest growth on the former will usually comprise larger individual tree specimens, and the rate of growth is likely to be more rapid than on the acid materials. Crops will be more bountiful, as a rule, on soils derived from more or less calcareous materials than on those derived from more acidic rocks. This is especially true if leaching has not extended to too great a depth. For example, the Miami soils of the North Central States are derived from a glacial till composed of as much as 60 percent of limestone and dolomite materials mixed with granite, gneiss, shale, sandstone, and many other kinds of rocks. Miami soils are productive and maintain much of their native fertility for a long period. They are very responsive to fertilization and good agricultural methods. On the other hand the Lordstown soils, derived entirely from acid shales and sandstones, are far less productive and need considerable fertilization before producing good yields. The Gloucester soils of New England and New York are derived from glacial till composed almost entirely of fragments of granite and gneiss. These soils are responsive to fertilization, but must receive fertilizer applications every year if their productivity is to be maintained. Their natural fertility for crops is far less than that of the Miami soils.

The residual effect of limestone on soils has its limits. For example, in warm-temperate and subtropical regions the prevailing type of weathering has so completely removed the lime and absorbed calcium from the soils that their fertility is greatly reduced. Eventually soil-forming processes overcome the beneficial effects and to a less extent the detrimental effects of parent materials.

Effects of parent material are far more important on young and imperfectly developed soils than on old ones. Freshly deposited alluvium is an excellent example of this fact. Alluvium washed from the soils of the western plains and of the prairie section of Iowa and Illinois have an extremely high natural fertility and will maintain a high state of productivity over a long period of years under suitable moisture conditions. On the other hand alluvium washed from old Red and Yellow soils exclusively has a lower natural fertility and can be made to maintain a similarly high state of productivity only by constant fertilization. Few if any large river systems draw all of their materials from naturally fertile or naturally infertile soils. Alluvium is usually a mixture of both of these kinds of materials and of freshly powdered rock as well. Productivity will vary more or less

with the proportion of rich and poor materials, with drainage conditions, and with the adaptability of specific crops to specific soils.

CLIMATE AS A FACTOR IN SOIL FORMATION

The climate is directly or indirectly responsible for variations in plant and animal life, for major soil differences, for the shaping of land masses thrust above the sea by movements of the earth's crust, and to a certain extent for the character of many important rock formations.

Climate influences soils both directly and indirectly. Directly it affects the type of weathering of rocks and the removal and redeposition of materials by water, wind, and glaciers; and it is responsible for the establishment of percolation of water through the soil. Regions of high humidity have more highly leached soils than those of semiarid and desert regions, and for this reason the chemical nature of the soils is radically different. In humid regions most soils are more or less acid in reaction and with few exceptions contain very little free lime (calcium carbonate). On the other hand soils of the deserts are leached but little and usually contain more or less lime and, in many cases, some soluble salts. These effects are in large part directly attributable to climate. In the arctic regions where substrata are frozen throughout the year and where upper horizons freeze and thaw during warmer seasons, there is considerable mechanical mixing of the soil horizons, and the soils remain in a poorly drained condition most of the time.

The most important direct effects of climate are on the weathering of rocks and alteration of parent material. These points have already been discussed in some detail. It is largely this direct influence of the climate on parent rocks which is responsible for the development of enormous areas of Laterite and old Red soils in the Tropics. Many of these materials are true soils, but some of them are the parent materials of soils now formed or in process of formation. In some instances Laterites are true soils, and in others they are merely the parent materials from which new soil profiles are now developing.

The climate within the soil, or soil climate, may be quite unlike that of the air above it. The content of carbon dioxide is considerably higher in soil air than in ordinary air, since it is constantly being produced by plant roots and other living organisms. Except in exceedingly dry soils or in the immediate surface of ordinary soils, the soil air is saturated with water vapor. When covered with vegetation, especially forests, the surface layer of soil is more moist than when cultivated. In fact the clearing of soils and their exposure to the sun may greatly reduce the activity of micro-organisms, especially in the Tropics.

Soil climate, especially that of the surface soil, is profoundly affected by relative atmospheric humidity. Where the average humidity approaches complete saturation (90 to 100 percent) soil climate is more moist than when the average is 60 percent or less. The effects of relative humidity are especially noticeable in China (*405*). On the Kweichow Plateau and in parts of Kwangsi and Szechuan the relative humidity for the entire year averages approximately 95 percent, and soils are in an almost continually moist condition in spite of the fact that the rainfall is less than in some other regions where average

humidity is lower. A direct result of this difference in humidity is the formation of Yellow Podzolic soils very similar to those of the southern United States. In the Province of Yunnan, adjoining Kweichow on the west, relative humidity averages from 60 to 70 percent for the year, but the rainfall is greater than in Kweichow. In spite of a greater rainfall, soil humidity is less than that in Kweichow, and as a result the dominant soils belong to the Reddish-Brown Lateritic and Red Podzolic groups. Similar conditions probably exist in mountainous regions of southeastern United States.

In southern United States soil humidity is encouraged in some places by flat or slightly depressed relief, and in these places soils of the Yellow Podzolic group are especially common, whereas on the better-drained areas Red Podzolic soils are dominant. Here topographic conditions have the same effect as differences in average relative humidity. Relative humidity is so high in the British Isles that the soils formed are somewhat similar to those of the United States just west of the Appalachian Mountains, although the annual rainfall of England is comparable to that found in parts of the Great Plains area, where the character of the soils reflects the influence of semiarid climatic conditions.

Effects of Rainfall, Temperature, and Wind

The total rainfall of a given region is not necessarily a measure of the effectiveness of water in soil formation there. Long-continued gentle rains will moisten the soil much more effectively than torrential downpours. Gentle rains soak into the soil, and the water percolates downward without severe run-off, except where the parent materials are almost entirely impervious. On the other hand, torrential rains tend to puddle the surface soil and prevent further penetration by water, and the rain runs off over the surface and into streams. If the land is not protected by vegetation or by erosion-control structures, soil erosion may be severe even on some of the less readily erodible soils. The more gentle rainfall characteristic of western Europe as compared with the United States accounts in part for the relatively small amount of soil erosion in England, France, and Germany. Gentle rains are more characteristic of humid regions than of semiarid and arid climates, where torrential downpours are the rule. Heavy thunderstorms during summer months in humid regions are an exception to the rule, but their effects are partly offset by the absorptive qualities of the soils engendered by dense vegetation.

High average annual temperatures encourage the rapid weathering of parent rocks and soil materials. In general the speed of chemical reactions approximately doubles for each rise of 10° C. in temperature. Hydrolysis, carbonation, and other forms of chemical weathering are extremely rapid in warm regions, especially if those regions are humid. In dry hot regions dehydration is important and hydrolysis, hydration, and carbonation are slowed down. These processes are active only in deeper horizons where soils are protected from the burning rays of the sun and from the evaporation effects of winds. In cold regions, especially if they are humid, soils are frozen during several months of each year, and in arctic regions deep substrata are permanently frozen. Freezing prevents the percolation of water through the soil and so

slows down soil-forming processes. In the tundra, processes of soil development are reduced to a minimum. In cool-temperate regions they can proceed actively only during the warmer months. Structure of soil is greatly modified in cool-temperate and temperate regions by freezing and thawing during transitional periods between summer and winter. Freezing and thawing of wet clays tend to form the material into aggregates.

In soil formation, wind acts as a drying agent and as an agent of erosion. Moving air will absorb more water than quiet air, so that in windy regions soils dry out much more rapidly than in regions of calm. The effect is accentuated if the average relative humidity is also low.

Wind erosion amounts to very little in regions of heavy rainfall and dense vegetation, but it is extremely important in the desert and to a less extent in semiarid regions. Winds pick up fine particles of soil and blow them from the deserts to nearby areas where vegetation is more dense and is able to hold soil in place. For this reason deserts are characterized by large expanses of bare rock, by drifting sand dunes, the grains of which are too heavy to be carried far, and by desert pavement.

Desert pavement is an accumulation of gravelly or stony rock fragments on the surface of soils. It is seldom more than an inch or two in thickness. Desert pavement is the coarse residue remaining on the surface after the fine particles of soil have been blown away by the wind. When it becomes thick enough to cover the soil completely it prevents further wind erosion. It will form only in places where the soil is composed of a mixture of fine-grained and coarse-grained materials. For this reason we do not find desert pavement on loess deposits or on silty or clayey alluvial materials. It is not common on soils derived from uniform-grained sandstones but develops readily where soils are derived from conglomerates or interstratified gravels, sands, silts, and clays of alluvial fans.

LIVING ORGANISMS AS A FACTOR IN SOIL FORMATION

Biological Activity

Two of the chief functions of plant and animal life, so far as soil profile development is concerned, are the furnishing of organic matter for the soil and the bringing in of plant nutrients from the lower layers to the upper ones. It may be said that there is no soil without organic matter. The organic-matter content of soils varies widely. Certain peats and the organic mats of some of the forest floors consist almost entirely of organic materials. On the other hand some of the desert soils contain only a small fraction of 1 percent of organic matter. The effects of organic matter upon soil profiles are also extremely variable. The primary source of soil organic matter is the vegetation that develops on it and modifies the color of practically all soils. Higher plants, such as grasses and trees, drop their dead leaves and trunks on the surface, and these furnish an enormous quantity of organic material over a long period. The roots of these same plants

permeate the soil, making it more or less porous and penetrating it sometimes to depths of many feet. The decay of roots, especially those of grasses, provides a large amount of organic matter for the soil. Organic material from grass and tree leaves is eaten by worms and mixed by them with the mineral soil.

Deep-rooted plants, such as some of the trees and grasses, bring water from deeper horizons to the surface and into the stems or trunks and the leaves of the plants. With this water there is always a certain amount of dissolved mineral material, particularly of more or less soluble bases, some iron and alumina, a little silica, and many other elements in smaller amounts. When the leaves fall and the plants themselves decay, these minerals are returned to the surface of the soil, and in this manner an important upward movement is established from deep horizons and parent materials to the surface. The process tends to keep the soils in a productive state, and the plants thus assist in the perpetuation of conditions under which they can exist.

If the vegetation is deep-rooted, water will pass through the surface soil more readily than where there are shallow-rooted plants. Thus, other things being equal, there is more leaching under deep-rooted trees than under shallow-rooted trees or grass. Water that falls on the surface tends to be quickly absorbed by these roots, and the water thus absorbed is withdrawn before it can permeate the soil and carry colloids and dissolved materials to deeper horizons. In humid forested regions rainfall is sufficient to overcome this effect, but in grassy areas of subhumid and semiarid regions water that falls on the surface seldom makes contact with water of deep substrata.

The decay of forest debris causes the formation of organic acids of various kinds, including particularly carbonic acid. These acids in solution hasten the leaching processes of soils and soil materials, and basic elements are rapidly leached away. It is the rule, then, rather than the exception, to find more or less strongly acid soils in humid forested regions. Desert vegetation is very scanty, as a rule, and contains little organic matter. Vegetation plays a less important part in the formation of Desert soils than of the soils in humid forested regions and especially in those of the subhumid and semiarid grasslands.

Animals play a role of secondary importance in soil formation, but their total influence is very great. They furnish one step in converting plant remains into soil organic matter, inasmuch as plants directly or indirectly furnish the food for animals and the excreta of the latter are returned to the soil, where they are further transformed. Barnyard manure is an important source of organic matter in agricultural soils, and in some countries human feces are equally important in this respect.

Burrowing animals, such as various kinds of rodents found in nearly all regions, aid in mixing various horizons of soils together and in supplying a certain amount of fresh parent material to surface horizons from which leaching in some soils is taking an extensive toll of plant nutrients. Earthworms feed on soil organic matter and thoroughly mix soils in which they live. They move and enrich many tons of soil to the acre each year, and they thrive especially well in moderately acid to moderately alkaline soils. One of the many indica-

tions of potentially productive soils is the presence of plenty of well-nourished earthworms; although in productive soils of arid regions the moisture is frequently insufficient for worms to exist. When such soils are irrigated, earthworms eventually establish themselves and assist in promoting crop production. Following rains in humid regions, pastures and cultivated fields are liberally sprinkled with worm casts, which contribute to the fertility of surface horizons. The burrows of worms and small mammals in many places reach deeply into the earth, and the excavated material is spread out over the surface. When the burrows are abandoned, surface soils, rich in organic material, find their way to deeper horizons as fillings for these cavities. It is possible for roots to make rapid growth through some of these relatively rich materials and to penetrate more deeply into more or less impervious substrata than might otherwise be possible. Animal burrows in desert and semiarid regions are especially noticeable because they are not completely covered by vegetative growth, but they are probably equally important in humid regions where forests dominate the landscape.

Micro-Organisms

Micro-organisms play an extremely important part in the development of soils and their preparation for the growth of higher plants. In some cases micro-organisms tend to encourage the growth of certain kinds of plants, whereas some forms are responsible for the destruction of other plants.

One of the most important functions of micro-organisms is that of changing raw vegetable waste into soil organic matter. Putrefactive bacteria and various kinds of fungi cause the decay of dead leaves and other plant remains and aid in their incorporation into the soil as organic matter. Microscopic animals (protozoa and other forms) live on some of these plant remains and help convert them into soil material. Some nitrogen-fixing bacteria live in symbiotic relationship with plants (usually legumes, such as clover and alfalfa), collect nitrogen from the air, and fix it in a form that can be used by higher plants. Nonsymbiotic nitrogen-fixing bacteria fix a still larger amount of atmospheric nitrogen in the soil. In general, fungi are more abundant in forested regions than bacteria, and their waste products are radically different from those left by bacteria, as indicated in table 1 (*15*). Conversely, bacterial activity is greater in grasslands than that of fungi. Nitrifying bacteria assist in producing nitrates from proteins and other nitrogen compounds, so that they are available for the use of higher plants.

Table 1.—***Chemical composition of fungous and bacterial residues***

Residue	Ether extract	Alcohol extract	Hot-water extract	Hemi-cellu-lose	Cellu-lose	Lignin
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Dead soil fungus (*Pseudomonas fluorescens*)	4.63	2.56	8.46	Trace	Trace	14.5
Dead soil bacteria (*Alternaria* sp.)	.54	2.98	5.29	9.32	5.19	29.0

RELIEF AS A FACTOR IN SOIL FORMATION

The influence of relief upon soil formation is due to its controlling effect upon drainage, run-off, and other water effects, including normal and accelerated erosion. Differences in relief may radically affect moisture and air conditions within the soil. Theoretically the water falling on a perfectly level surface of a permeable soil material will be absorbed uniformly into the soil until the latter becomes saturated and will then collect on the surface as a thin sheet. Since perfectly flat surfaces and uniformly permeable soil materials are practically unknown, the rain water collects in depressions, however slight, and penetrates some materials more rapidly than others. Even if parent materials are exactly the same, slight undulations in the surface will encourage the water to drain away from the high spots to collect in the low spots, and soils in the latter situations will receive more water. On moderate and steep slopes the tendency toward run-off is normally greater than the tendency for water to penetrate the soil, and good or excessive drainage is found in such positions. Only during and immediately after rains are these soils wet or very moist. Soils in these positions are subject to more or less severe erosion, especially if they have been cleared of their native vegetative cover, if they occur in arid regions where vegetation is sparse, or if, for some other reason, plant growth is scanty.

Soil profiles on steep slopes are usually not strongly developed, except in some regions of heavy rainfall, warm climate, and dense vegetation. This stunting of soil development is due to (1) rapid normal erosion, (2) the reduced percolation of water through the soil, and (3) lack of water in the soil for the vigorous growth of plants responsible for soil formation. With equal rainfall and similar parent material, the soil climate is more humid on gentle than on steep slopes and still wetter on flats and in depressions.

The degree of profile development taking place within a given time on a given parent material and under the same type of vegetation seems to depend largely on the amount of water passing through the soil. With medium and moderately heavy textured parent materials, therefore, the most strongly developed soil profiles are found on flat areas where there is a sufficiently permeable substratum to carry off the excess ground water slowly. In poorly drained and waterlogged areas may be found strongly developed soils of a special type. Soils of flat areas in the humid temperate zone eventually reach a stage of senility in which they are characterized by leached surface horizons and extremely heavy subsoils of claypan or hardpan types—the Planosols. Convex, gently sloping areas in the same region have a similar sequence of horizons but are without the extremely heavy development in the subsoil. These are sometimes called mature or normal soils. Normal erosion on them is just about sufficient to keep pace with soil-forming processes, so that they neither take on the characteristics of senility nor are sufficiently eroded to be kept in a youthful stage of development. Figure 2 illustrates a sequence of profiles varying in characteristics on account of differences in relief.

It has been pointed out that soils in semiarid and arid climates usually contain more or less lime in the profile, especially in the lower

horizons. They also normally contain some of the more soluble salts, such as the chlorides, sulphates, bicarbonates, and carbonates of sodium and other alkali or alkaline earth metals. On convex surfaces, where drainage is good, gradual leaching of rain water removes these salts to deep horizons, below the true solum,[3] where

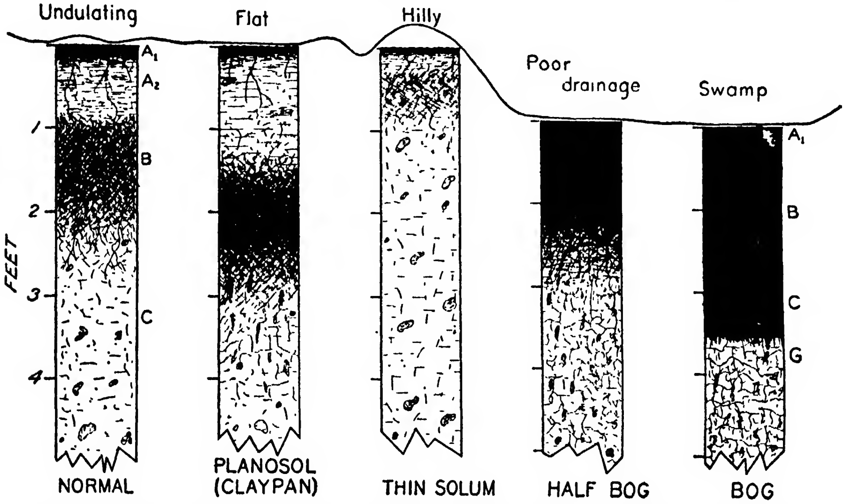

Figure 2.—Soil profiles developed from similar parent materials but varying in surface relief. Note that a shallow soil is developed on hilly land because of excessive run-off and erosion; whereas the flat upland has little or no erosion and a highly leached upper soil, with a dense claypan in the lower part of the soil. Examples from the detailed soil classification, reading from left to right, include Miami, Crosby, Rodman, Brookston, and Carlisle soil series (*195*).

they have no bad effect on crops. On concave or flat surfaces, where drainage is imperfect, saline solutions are held within capillary reach of the solum and the salts are precipitated on or near the surface by the evaporation of the capillary water. For this reason, microrelief (minor variations in relief) is extremely important on soils of the semiarid and arid regions, especially where irrigation of the land tends to raise the ground-water level.

In semiarid and arid regions well-drained soils of flats and depressions receive enough moisture shed by soils of steeper slopes nearby to support more vegetation, and hence they accumulate more organic matter. As a result, there are frequently found in depressed but well-drained areas soils characteristic of higher rainfall regions than those in close association with them on slightly higher ground. Microrelief may thus produce a subhumid soil climate in semiarid regions.

Not only is the degree of slope important, in that it affects moisture conditions in the soil, but its direction is also significant, especially on the great plains and deserts. On moderate to steep northerly slopes of the Northern Hemisphere, the sun's rays are much less effective in heating the soil and evaporating the mositure than on southerly slopes. As a result soil moisture is higher on the northerly slopes,

[3] The solum is the true soil or that part of the soil profile that shows the effects of soil-forming processes. It lies directly over the parent material (see Glossary).

vegetation is denser, and the soils are darker. In critical rainfall areas one finds forests on northerly slopes and grasslands on summits and southerly slopes, with correspondingly great differences in soil.

In other places the effects of slope direction may be due to rainfall produced when warm winds are cooled by passing over high hills or mountains (orographic rainfall). For example, summer storms on the Rocky Mountains originate near the crests of ridges and drift eastward, so that more rain falls on eastern than on western slopes. In such regions may be found successively, from the foot of the mountains to the summit, a succession of soil characteristics similar to that found in passing from the arid portion of the Great Plains to the humid forest soils of the North Atlantic States.

TIME AS A FACTOR IN SOIL FORMATION

Time is necessary for the development of soils from parent materials. The length of time required for the formation of a given type of soil depends largely on the other factors involved. Certain acid soils characteristic of humid regions form in a relatively short time on acid materials containing an abundance of quartz sand and a covering of dense forest growth, especially under a cool and very humid climate. Perhaps 100 or 200 years might be sufficient under such conditions. If lime is present in the sandy material the time requirement is greater, and if the texture of the parent material is very heavy, a very long time would be required, because of the difficulty of establishing and maintaining a free downward movement of water through the solum and into the parent material.

Time is a very important factor in the formation of parent material. For example, two soil series in eastern Indiana are both developed on highly calcareous glacial till. The Miami soils are developed from material which has been leached free of lime to a depth of about 30 inches, while the Russell soils, with very similar profiles, are developed on till which has been leached to a depth of about 50 inches. The difference in age of these materials is represented by the difference in time between the deposition of the Early and Late Wisconsin glacial drifts and would probably be measured in thousands of years. The Illinoian drift, in the same State, is leached to a depth of 10 feet or more and represents a still longer time for the preparation of soil material.

It must be remembered, however, that the so-called normal soils are developed on gently sloping land subject to continuous, if slow, geological erosion. Soil and parent-material formation are approximately balanced by gradual erosion.

Soils of flat areas, elevated above present stream overflow, may be much older in point of time and soil development than those on slightly higher and more sloping areas. For example, soils of the Bethel and Delmar series of eastern Indiana (in the Miami-Crosby-Brookston area of the soil map) have much more strongly developed profiles than those of the Miami and Russell series, which are considered normal for the region. Their profiles have not been truncated by erosion, nor, in typical areas, have they received new material. They are old in terms both of soil morphology and actual years. They are classified as Planosols and have characteristic claypan subsoils.

Soil materials of formerly flat and now dissected areas of the Tropics and warm-temperate regions are extremely old in years, even though relatively young from the geological viewpoint. Many, if not most, of them date back to glacial times and even to the more remote Pliocene epoch of the Tertiary period, variously estimated at from 1 to 6 million years ago. Flat, ancient peneplains (areas which have been reduced by erosion almost to base level) of these regions have soils some of which date back, as such, to those ancient geologic times. Many of these soils are in a senile stage of development and are extremely infertile because of long leaching of important nutrients without renewal from fresh parent material.

The time required for the development of a normal soil is probably greater in dry regions than in more humid ones. Where rainfall is light and vegetation scanty, the desert winds are active in removing and redepositing soil materials. Hard lime accumulations many feet in thickness have developed in these desert regions, but the time required must have been great.

Soils of high and steep mountains are normally young in terms of years and stage of development because of rapid erosion, and the age of soils on flood plains is also slight because of the almost continuous accumulation of materials. Many young soils of the mountains as well as of the flood plains are very fertile, but steepness, shallowness, and stoniness in the mountains limit their usefulness for agriculture. Young soils of alluvial flood plains include much of the most productive soil of the world.

One cannot make any useful statement in terms of years, however, regarding the rate of soil formation in general. Some soils have formed very rapidly, in a few years, and others exceedingly slowly. It is also clear that there is no direct relationship between the age or maturity of soils and the age of the rocks underneath.

SOIL-FORMING PROCESSES AND THE ZONAL, INTRAZONAL, AND AZONAL SOILS

On the basis of common characteristics, local soil types and series may be grouped logically into various broader groups as described in the article Soil Classification. These groups fall under the heads of (1) zonal soils, (2) intrazonal soils, and (3) azonal soils.

Zonal soils are those that owe their most important characteristics to the effects of the climatic and biological factors acting on well-drained but not excessively drained parent materials of mixed mineralogical composition over a long period of time. Pedologists speak of them as normal soils.

Intrazonal soils owe their distinguishing characteristics to the overbalancing effects of parent material or relief. In some the parent material is of a special type and is able to outweigh the effects of the biological, climatic, and relief factors. In others relief outweighs other soil-forming factors.

Azonal soils are those that have few or no soil morphological characteristics. Their characteristics are similar to those of the parent materials of which they are composed. These materials have either not been exposed long enough to soil-forming processes or are too resistant to them for soil characteristics to develop. Fresh alluvium,

dry sands, and the soils on steep rocky hillsides are the principal examples.

SOIL-FORMING PROCESSES [9]

Zonal, intrazonal, and azonal soils of various great groups owe their characteristics to various soil-forming processes of which the most important are (1) calcification, (2) podzolization, (3) laterization, (4) salinization, desalinization, alkalization, and dealkalization, (5) formation of peat and poorly drained soils, including gleization.

Calcification

Pedocals

The calcification process results in the redistribution of calcium carbonate or carbonate of lime in the soil profile without complete removal of it. Magnesium carbonate accumulates along with the carbonate of lime. The areas so affected are normally those of restricted rainfall—varying from approximately 25 inches or less in the Temperate Zone to approximately 45 inches or less in the Tropics—and the dominant vegetation is grass or brush. Since the rainfall is low, the percolation of water through the profile is not sufficient to remove wholly the calcium carbonate that existed in the parent material or was produced by reaction between carbonic acid and the calcium hydrolyzed from silicate minerals. The usual result is the development of an accumulation of calcium and magnesium carbonates at some point in the profile below the surface, approximating the depths to which surface waters most frequently percolate. Marbut (*240*) called these soils Pedocals (soils with lime accumulation).[10] While this is the normal formation, a calcium-carbonate deposit does not necessarily always occur. A secondary result of calcification is that the calcium tends to keep the colloid (fine clay) in a somewhat granular condition, and there is therefore relatively little downward movement of the colloid in the profile.

It has been possible to arrange a multitude of Pedocal soil series into a few great groups, using their color, organic-matter content, depth, and amount of lime accumulation as criteria for making combinations. The group names are largely of Russian origin, and their application to soils of the United States was first made by C. F. Marbut, who modified some of them. In the present classification further modification seems advisable. They are: (1) Chernozem (black earth); (2) Chestnut soils (dark-brown soils); (3) Reddish Chestnut soils; (4) Brown soils; (5) Reddish Brown soils; (6) Sierozem soils; (7) Desert soils; (8) Red Desert soils.

Chernozems are very dark brown or black in the upper 2 to 4 feet and have slightly acid or slightly alkaline reaction and a nutlike structure. Organic matter is high, and the soils are naturally very fertile. A yellowish-brown or grayish-brown transitional horizon of a few inches separates the dark surface soil from the very calcareous horizon of lime accumulation. The lime is silty in character, includes more or less magnesium carbonate, and occurs as irregular soft masses and vertical streamers, extending to a depth of several feet in many places. Parent material below is less calcareous and in places contains no free lime. Accumulated lime comes partly from lime originally present in the materials and partly from the carbonation of calcium and magnesium silicates.

Chestnut, Brown, and Sierozem soils have prismatic, dark-brown, brown, and light brownish-gray upper horizons, respectively, and progressively less organic matter in the order listed. The thickness of the surface soils also becomes less in the order listed, and the lime accumulation usually reaches its maximum development in the first two, except in cases of extremely old Sierozems and Red Desert soils. All typical members of these groups except the Sierozem and Red Desert soils have little or no free lime at the surface, but the brown horizons in places are calcareous in their lower portions. Calcareous dusts sometimes accumulate sufficiently to render calcareous the surface inch or two. Reddish Chestnut and Reddish Brown soils have a dull reddish tinge in surface horizons and reddish-brown or red heavier subsoils above the horizon of lime accumulation.

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[9] The following pages are somewhat more technical in character than the preceding general discussion and are intended primarily for students and others concerned with soil science.

[10] From a technical standpoint the use of the term "lime" for calcium and magnesium carbonates is incorrect, but the term is very commonly used in this way among laymen and pedologists alike.

Chernozems occupy grasslands with subhumid climate, and Chestnut, Brown, and Sierozem soils occupy regions with progressively drier climate and scantier grass cover. Sierozems have little grass and some small shrubs and are in semidesert regions. Reddish Chestnut, Reddish Brown, and Red Desert soils support a greater percentage of shrubs and less grass than the corresponding groups farther north. True Desert soils have but a scanty growth of perennial shrubs and certain scattered drought-resistant grasses.

Desert and Red Desert soils are in the true deserts—the first in temperate regions and the latter in subtropical and tropical regions. They are usually calcareous to the surface but more so in substrata. Winds remove finer particles from surface horizons and leave a protective desert-pavement cover of small and large rock fragments. In many of the Desert soils the lime accumulation takes the form of hard concretions or stony formations (caliche) and attains a thickness of many feet in places. Physiographic evidence indicates that some of these lime hardpans or crusts were formed in poorly drained depressions tens of thousands of years ago and have become well-drained during a geologically recent cycle of erosion.

According to Nikiforoff's hypothesis (*281*), the reddish heavy subsoil of Red Desert soils is due to weathering of minerals in deeper horizons under the influence of moisture which percolates downward during brief rainy periods. This assumption might also be made in regard to the heavy subsoil horizons of the Reddish Chestnut and Reddish Brown soils.

Black crusts of iron oxide form protective coatings on rocks and pebbles of the hotter deserts and are known as desert varnish.

The calcification process not only connotes the accumulation of lime in the soil but also the adsorption of calcium ions by the colloids. (See General Chemistry of the Soil, p. 911.) Grasses and other plants requiring relatively large amounts of bases, particularly of calcium, bring these bases to the surface and, through decay, replenish the losses of leaching. For this reason the surface soils are seldom strongly acid—usually approximately neutral—and may be even faintly alkaline. When colloids are high in calcium (and to a less extent in magnesium) the reaction will usually range from slightly acid to slightly alkaline, and there will be an abundance of calcium available for crops. Brown Forest soils presumably owe their lack of eluviation and illuviation to this kind of calcification and are limited to areas with a forest vegetation having a particularly high content of bases in its leaves. Rendzinas are also calcified but, in spite of calcareous parent material, do not always contain free carbonate of lime.

Prairie Soils and Degraded Chernozem

Under a somewhat higher rate of rainfall than is characteristic of lime-accumulation soils (Pedocals) the mean flow of water through the profile may be sufficient to produce, under abundant grass cover, a soil profile containing no calcium carbonate accumulation and yet with a high degree of base saturation. Such soils may have some free lime in the parent material. They are the most fertile and productive of the Corn Belt. They exist over large areas, particularly in central United States, and are known as Prairie soils. They have profiles similar to Chernozem and Chestnut soils but do not have any lime accumulation. There is no sharp division in areas or profile characteristics between the soils having a zone of calcium carbonate accumulation and the Prairie soils, which have none. The colloids of Prairie soils are usually high in calcium even though no free lime is present. Furthermore, as rainfall increases and grassland gives way to forests, the calcified soils merge into the Gray-Brown Podzolic, the Red and Yellow Podzolic, and other soils characteristic of forested regions. The northern Prairie and Chernozem soils merge with the Podzols in cooler regions. Reddish Prairie soils contain less organic material than Prairie soils and occur in warmer climates. They grade into Reddish Chestnut soils on the one hand and into Red and Yellow Podzolic soils on the other.

When forests invade the Chernozem grasslands under the influence of changing climate, podzolization becomes active, and the dark color of the Chernozem begins to become lighter, especially in the lower part. Upper horizons begin to take on the character of Podzols and Gray-Brown Podzolic soils before the lime horizon is entirely leached away. These are known as Degraded Chernozems.

The general effect of moderate rainfall, particularly when accompanied by grass

cover, is to produce very fertile soils. Calcified soils are usually extremely productive if they receive sufficient water for crops. Even Desert soils of low organic content produce bountiful crops if irrigated and drained.

Podzolization

Podzols and Brown Podzolic Soils

Podzolization is dominant in areas of high humidity and forest vegetation and is one of the most important processes in the formation and modification of the Pedalfer soils. The process comprises two phases. One of these is the accumulation of a peaty mat of organic matter on the surface and removal of clays and iron compounds from an upper to a lower layer, with consequent whitening of the soil layer immediately beneath the surface organic matter. The translocated materials are partly assorted (fractionated), and different ingredients are deposited in different horizons of the profile. Suspended organic matter is deposited just below the bleached layer, together with a considerable quantity of iron and aluminum compounds. Iron compounds are deposited next, often to serve as cementing agents, while clays are carried still deeper by the filtering waters. There is considerable overlap between these horizons. This process results in the formation of members of the great group of soils called Podzols. Typical profiles are usually found on coarse-textured parent material. Table 2 shows the general profile characteristics of Podzol soils.

Table 2.—*General characteristics of Podzol soil profiles*

Horizon	Thickness	Description
1. A_{00}	1 inch or more	Loose leaf litter.
2., 3. A_0	½ inch or more	Fermenting leaves, twigs, and wood. Humified acid organic matter.
4. A_1	¼ inch or more	Dark-gray mixture of acid humus and mineral soil. Usually very thin and entirely lacking in many places.
5. A_2	½ inch to 30 inches or more	Whitish-gray or pale pinkish-gray, highly leached, acid, phylliform (composed of very thin plates or laminae) soil of light or medium texture.
6. B_2	2 to 10 inches	Dark coffee-brown silty or loamy soil containing much organic matter and iron oxides. Sometimes cemented.
7. B_3	1 to 10 inches	Yellowish-brown or brownish-yellow loam or clay loam with little organic matter.
8. B_{31}		Transition and parent material usually more or less acid and sandy, but may be somewhat calcareous in places.

The A_2 and B_2 horizons are usually very distinct, but their thickness varies extremely within short distances. In some places there is a thin transition layer between them. The soils have a low natural fertility but some of them respond well to fertilization.

Under certain local variations in soil climate and where soils have been disturbed within a relatively short time, the whitish A horizon is entirely lacking, and the dark brown B_2 horizon, somewhat lightened in color by admixture with the A_2 horizon, appears directly under the A_0 horizon. The name Brown Podzolic soils [11] is proposed for this group. Gloucester series soils are excellent representatives of this group, while Hermon soils, developed on the same kind of materials, are good representatives of the Podzol group.

The organic layer overlying Podzol soils is usually so strongly acid and of such low base content that bacteria act upon it only very slowly. Fungi usually dominate the microflora. It is possible also that in some cases toxic organic constituents, such as tannic acid, may restrain decomposition. As the acid organic matter slowly decomposes and a part of it dissolves in the presence of iron-bearing minerals, the solution of iron in the ferrous state is promoted. Water carrying such compounds in solution or in a state of dispersion may also carry other organic material or dispersed inorganic soil colloids. As this water percolates through the profile it often encounters soil layers less acid than the surface, and oxidation more readily takes place, rendering the iron less soluble. Such

[11] See Soil Classification, p. 979.

material as may be precipitated under the slightly changed conditions serves as a filter mat to remove still more material from the percolating waters. This may account for the high sesquioxide and organic matter content of the upper portion of the B horizons of many Podzols. The total clay content of this horizon is not usually high, but it is usually composed of a high percentage of aluminum and iron hydroxides and a very low content of silica. Surprisingly large quantities of highly dispersed organic matter are frequently found in the C horizons of such soils.

It is possible for the removal of fine material to take place without much fractionation (partial assortment), and this results in the development of a grayish-brown, whitish, or gray layer in the upper part of the mineral soil without the formation of a very dark brown B_2 horizon. Such a process is also called podzolization, but it does not produce profiles in all respects characteristic of the Podzols. The tendency to fractionation may also be evident without being sufficiently effective to produce typical Podzols. In consequence we have podzolization, as a process, operating to produce modifications in soils of several broad groups wherever sufficient rainfall occurs to produce percolation of water through soil covered with acid organic matter. Podzolization is effective under both coniferous and hardwood forests and in temperate and tropical climates.

Gray-Brown Podzolic Soils

Gray-Brown Podzolic soils of forested humid temperate regions have certain features in common with the typical Podzols, but the profile horizons are less clearly defined. They have a surface covering of leaf litter, usually of deciduous trees; a dark, thin, mild (only slightly or moderately acid) humus, somewhat mixed with mineral soil; a grayish-brown, crumb-structured loamy A_1 horizon and a light grayish-brown or grayish-yellow loamy A_2 horizon; a moderately heavy, nut-structured, yellowish-brown, brown, brownish-yellow, or reddish-brown B horizon, becoming lighter-colored with depth. The total depth of the solum varies considerably but seldom exceeds 4 feet.[12]

Parent materials of Gray-Brown Podzolic soils cover a wide range of weathered rocks and minerals, and their character has an important bearing on their ultimate agricultural productivity. Perhaps half of the region of Gray-Brown Podzolic soils in the United States was formerly covered by glaciers, and these materials are variable in composition. Miami soils of Ohio, Indiana, Michigan, and Wisconsin and Honeoye soils of New York are among the best-known of the Gray-Brown Podzolic soils derived from glacial till, while the Chester and Sassafras soils of the northern Piedmont and the Coastal Plain, respectively, well represent the unglaciated members.

The Red and Yellow soils of warm regions, and even Laterites, also are subject to the podzolization process, but the decomposition of organic matter is still more rapidly accomplished and the leaching of bases is more complete than in Gray-Brown Podzolic soils. The fractionation of the colloid is still less marked than in either the Podzols or Gray-Brown Podzolic soils. That is to say, the chemical composition of the mineral colloids of all horizons does not vary greatly. The surface horizons may, however, be as completely bleached as the bleached horizons of typical Podzols. In fact, this is very commonly the case, even in the soils of tropical regions, provided the parent material contains at least a moderate content of quartz sand and silt.

Laterization

The soil-forming process called laterization is essentially the progressive hydrolysis of rock minerals, and its full development results in their conversion to silicic acid, aluminum hydroxide, and iron hydroxide or their more or less complete dehydration products—the Laterites. Since in general silica is more rapidly removed by solution than are iron oxide and alumina, a fully developed Laterite may consist of only aluminum and iron hydroxides, although the process is normally not complete in any soil. The ultimate decomposition products contain very little acidic material and, consequently, have little base-holding capacity. The Laterites are normally very deficient in plant nutrients and can only be used

[12] For further details see Baldwin (*23*), Marbut (*240*), Kellogg (*145*), and BALDWIN, MARK, SOME CHARACTERISTIC SOIL PROFILES IN THE NORTH CENTRAL STATES. Amer. Soil Survey Assoc. Bull. 7: 122–132. 1926. [Mimeographed.]

for the production of agricultural products by frequently repeated applications of fertilizers, the phosphate portion of which is rapidly rendered unavailable. On the other hand, since high temperature and high humidity favor plant production and also hasten laterization, Laterites and lateritic soils are often productive when fertilized or when conditions favor the accumulation of much organic matter on the surface. The fertility resulting from the latter condition rapidly disappears under cultivation.

Laterization, in its strictest sense, is a process of soil-material development—a process of rock weathering resulting in the formation of lateritic clays on which the podzolization process acts to form podzolic Red and Yellow soils characteristic of humid warm-temperature and tropical regions. Lateritic clays are basically red, with reticulate mottlings of red and light gray, buff or whitish; but some of them, where drainage conditions have always been nearly perfect, are a fairly uniform red color. They are usually thick and may reach a depth of as much as 100 feet in places where weathering has been active for many thousands of years. They develop from many different kinds of rock materials, including dark-colored fine-grained igneous rocks, granites, shales and loamy sandstones, arkose, and limestone residuum.

Soils derived from lateritic materials usually are more or less podzolized, especially if they contain moderate or high proportions of quartz sand or silt. Red Podzolic soils, of which there are many in the southeastern United States and in the West Indies, have up to an inch or two of leaf litter on the surface, with matlike development in places; a gray or dark brownish-gray humified mineral soil (A_1) up to 2 or 3 inches thick, a yellowish-gray, or light pinkish-gray more or less sandy A_2 horizon several inches thick; a red or brownish-red granular-structured clay B horizon, 1 to 3 feet thick, and reticulately mottled lateritic parent material, already described.

Yellow Podzolic soils develop under more humid soil conditions than the Red Podzolic soils, either because of impaired drainage or because of a higher atmospheric humidity, coupled with a high rainfall. The A_2 horizon is grayer and deeper in many places than that of the Red Podzolic soils and the upper B horizon is pale yellow instead of red. The lateritic parent material usually has a higher proportion of yellow in the color pattern.

Some Red and Yellow Podzolic soils are only slightly acid in reaction, while others are very strongly acid.

Laterite is supposedly the ultimate product of lateritic weathering, but this theory has not been proved conclusively. In many places it seems probable that kaolinlike (halloysitic or kaolinitic)[13] clays, with a silica-alumina molecular ratio of 2, are the ultimate stable product. The Laterite originally described by Buchanan (*296*) in India is a reticulately mottled, red, buff, and whitish clay from which some of the lighter-colored clays have been removed, leaving a more or less cellular structure. These clays harden into rock on exposure to the air. They are composed very largely of the hydroxides of aluminum and iron.

The ferruginous (high-iron) Laterites of Cuba and Puerto Rico (Nipe series) and of the Hawaiian Islands are uniformly dark brownish red in color, granular in structure and porous in constitution. They contain higher percentages of iron than normal Laterites. There are occasional seams of cellular ironstone in them and many shiny black iron-manganese concretions. These soils absorb water very readily, with little or no swelling, and can be plowed immediately after heavy rains. They have extremely low natural fertility and are subject to drought. True Laterites seem to have been developed under tropical conditions with alternating seasons of high rainfall and drought. They have been found in Puerto Rico and the Hawaiian Islands but are not known in the United States.

Soils in which the laterization process has become markedly evident but has not reached completion are known as lateritic soils. Their best-known representatives in the United States are the Red and Yellow soils of the humid South and Southeast, and they are very important in the West Indies. Most of them have been modified by podzolization. These soils are characterized by a colloidal fraction whose molecular ratio of silica to alumina is approximately 2. Material of this composition is very inert, having properties in common with those of the commercial clays known as kaolin or china clay. Such soil colloids sometimes have a submicroscopic crystalline structure characteristic of the clay minerals known as halloysite and kaolinite.

[13] Kaolin is common china clay, used for making chinaware. This clay contains 2 molecules of silica (SiO_2) for each molecule of alumina (Al_2O_3).

In most areas where Laterites or lateritic soils are dominant, there usually exist areas of less strongly developed soils in which, by reason of rapid erosion, or of deposition of alluvium or volcanic ash, fresh minerals are exposed to decomposition. Under such conditions, even in tropical areas of high humidity, a very complex mixture of soil types may be found.

Formation of Peat and Poorly Drained Soils (Gleization)

When soil parent material is nearly impervious to water or is so located topographically that water stands continually at or slightly above the surface, the plant growth, as it perishes seasonally, builds up a body of organic material known as peat. Peat deposits in bogs are particularly abundant in cool, moist climates where conditions are favorable for the growth of sphagnum and other mosses, but they also occur in warm-temperate and tropical regions and are sometimes composed largely of wood, grasses, or reed remains. Great peat deposits are found in Florida, Georgia, North Carolina, and Puerto Rico, as well as in the northern tier of States. Muck is peat in a more advanced stage of decomposition and usually has a greater mineral content. It is usually black or very dark brown in color, and some varieties produce high crop yields. Peat and muck are known collectively as Bog soils.

Under alternating wet and moist conditions iron compounds are reduced to soluble forms and the solubilities of calcium, magnesium, and manganese are increased. The usual effect is to produce a gray or bluish layer in deep soil horizons and mottling of yellow, brown, and gray streaks along cracks and root channels of upper horizons. In sandy material there may be produced soils which closely resemble Podzols in general character. These are known as Ground-Water Podzols, and in many places they have a hardpan of organic matter or ironstone at the mean level of the ground water. The process results in the formation of a wide variety of soil types intermediate between peat and Ground-Water Podzols. These include Wiesenböden (Meadow), Half Bog, and various Planosols, as well as Tundra and Alpine Meadow soils. Most imperfectly and poorly drained soils have more or less strongly developed profiles differing, as already indicated, from the normal soils of their regions. The bluish or greenish waterlogged horizons are sometimes called glei or gley, and the process by which they are formed is sometimes called gleization. In tropical regions poorly drained Ground-Water Laterites are developed under fluctuating wet and dry conditions. They are especially common on nearly flat areas.

Imperfectly drained soils in which the ground water is constantly draining away tend to become gray instead of bluish or greenish in deep substrata, and these soils in many places are better suited to cultivation when drained. This horizontal leaching and eluviation may be regarded as a phase of podzolization. The podzolized rice paddy soils of China are excellent examples of the combined effects of gleization and ground-water podzolization. Usually it does not pay to drain very strongly acid wet soils for cultivation, but those containing any appreciable percentage of lime are often quite productive when drained. Rice will usually produce well, if fertilized, on soils having a very wide range of acidity, but yields are likely to be low if bluish or greenish horizons (true gley) closely approach the surface.

Salinization, Desalinization, Alkalization, Dealkalization

Salinization

Salinization is the process of accumulation of various kinds of salts in the soil, including sodium chloride, sulphate, bicarbonate and carbonate, calcium sulphate (gypsum), and chloride; and sometimes magnesium sulphate and chloride or potash salts also may be present. When these various kinds of salts occur in appreciable quantities in the soil they are popularly known as alkali. White alkali is composed of one or all of the salts listed except sodium carbonate. Sodium and potassium carbonate are known as black alkali because they dissolve and disperse the organic matter which diffuses through the soil and colors it dark brown or black. The presence of sodium carbonate also tends to strongly disperse the inorganic colloidal material when water is present. As this dispersed mass of organic and inorganic materials dries, it forms a jelly and later a structureless impervious mass. It serves as a highly effective cementing agent when mixed

with the coarser soil grains. Salinization can occur on practically any kind of soil and gives rise to the development of saline soils—sometimes called Solonchak.

Saline soils are most common in imperfectly or poorly drained areas of semiarid and arid regions in depressions and in seepy spots. They are fairly common in old lake bottoms in these regions and on low alluvial deposits along seacoasts, even in humid regions. The salts are concentrated from the decomposition products of rocks that may contain only small quantities of such constituents as chlorine and sulphur, together with more abundant quantities of the basic elements sodium and calcium.

Salts usually accumulate in the soil by the evaporation of slightly saline capillary water or by the evaporation of salt water from the surface, as along the borders of salt lakes. In some cases salts are deposited in the subsoils—sometimes several feet underground. This is because the capillary movement is not usually very active more than 6 or 8 feet above the surface of ground water and evaporation takes place in the soil air. In some cases the very coarse texture of the soil prevents capillary water movement and evaporation takes place in the pores of the soil.

There are many different combinations of salts of various kinds in saline soils. In many of them sodium chloride is the chief salt, with only very small proportions of others. In others sodium sulphate, sodium carbonate, or some of the salts of calcium and magnesium may dominate, or the salts may be a mixture of approximately equal quantities of each. In some cases complex double or triple salts, such as hanksite—a compound containing sodium sulphate, sodium carbonate, and potassium chloride in definite proportions—may be present. If the salts are composed almost entirely of compounds of sodium, with possibly some potassium and other salts in lesser quantities, there is a tendency for the soil colloids to approach saturation with sodium and for the soil to become a sodium Solonchak. With a more abundant water supply these soils develop into alkali-claypan types sometimes called Solonetz. On the other hand, if alkaline-earth salts, such as calcium sulphate and chloride, are present in large quantities there is a tendency for the soil to change over into one of the normal zonal types such as Chernozem, if and when the salts are removed under improved drainage conditions.

Saturation of soil with sodium salts results in large amounts of sodium being absorbed by the colloidal clay. When such clays are leached by fresh water and the excess salts removed, hydrolysis of the sodium clay results in the formation of sodium hydroxide and later carbonate which causes individual clay particles to separate from one another when sufficient water is present, to form a jellylike mass. This is known as deflocculation and is a very common phenomenon leading to bad physical condition in soils after the greater part of the salts has been leached away.

Vegetation on saline soils is usually rather sparse and of specialized types, particularly if the percentage of salt is high. When there is more than 0.2 percent of the "white salts," most economic crop plants will be injured, and certain specialized types of vegetation will begin to appear. Very few agricultural crops will produce well when there is more than 0.5 percent of salts, but the salt-loving vegetation will be fairly abundant on such soils. These salt-loving plants are known as halophytes. There are also some plants which grow well on saline soils but almost equally well on normal nonsaline soils. These are described as being salt-tolerant. Surface soils with more than 3 percent of salts seldom produce plants of any kind except deep-rooted varieties that were established before the accumulation of salt took place and have been able to extend their roots to deep levels where salt concentrations are not so great. Aside from the actual concentration of soluble salt present, sodium carbonate tends to produce such a strongly alkaline condition (high pH) of the soil solution that few plants can survive when more than a few tenths of 1 percent of this constituent is present.

Desalinization and Alkalization

Theories concerning these processes are many, and at present it is not known with certainty which are correct and which are wrong. The following theory is most commonly accepted, in whole or in part, by pedologists: When drainage conditions on saline soils are improved and when they are irrigated or receive fresh water from some other source, the salts are gradually dissolved and leached away. As long as there is an abundance of salts in the soil the colloidal clay

materials are held more or less aggregated, and the soils are usually sufficiently porous for water to pass through rather readily. So long as sufficient salts remain, this structure is maintained, and the sodium-saturated colloids are not able to hydrolyze. If there is an abundance of calcium in the soil in the form of soluble salts or as finely divided lime the condition of good percolation is maintained, and the soil gradually changes over to one of the zonal types, such as Chestnut or Chernozem. If, on the other hand, the calcium content is low and the sodium content high, the sodium clays will hydrolyze to form free sodium hydroxide as soon as the greater part of the salts has been removed. This results in the deflocculation of the colloidal particles, and the soil becomes sticky, jellylike, and impenetrable to water, thus restraining the further improvement of such soils or actually rendering them unproductive even though the soluble salt content may be below the percentage limit normally toxic. The soil solution becomes very strongly alkaline, and very few plants can survive under these conditions. Accompanying the deflocculation of the clays, organic matter is dispersed and colors the entire soil mass dark brown or black. In this stage the soil is popularly known as black alkali. Some sodium carbonate is formed through the reaction between sodium hydroxide and carbon dioxide of the air.

Following the deflocculation of the clays, there is a tendency for them to migrate downward through the soil and to collect in slightly lower levels, leaving a coarser-textured material at the surface as a very thin coat. The soil in this stage of development is sometimes described as an alkali-claypan type. The clay horizon is extremely heavy and plastic when wet and very hard and columnar or prismatic in structure when dry even though the percentage of clay may not be very high. The columns or prisms tend to become rounded at the top, and the gradual horizontal movement of water over them during wet weather tends to cause the development of a white or light-gray leached silty layer from which organic and mineral colloids have been removed by the water. Among pedologists these alkali-claypan soils are known as Solonetz, a term which has been adopted directly from the Russian.[14] The process is known as solonization among some pedologists.

The typical Solonetz has many points in common with the claypan soils (Planosols) of the Gray-Brown Podzolic soil region and with those of the Red and Yellow Podzolic soil region as well. They may be compared, for instance, with the Crosby soils of Ohio, Indiana, and neighboring States. The Crosby soils have claypans which do not, however, have well-defined columnar structure in the subsoil, but there is an accumulation of grayish silty material in the lower part of the A horizon. The Crosby soils are acid to a considerable depth and differ in most other respects from the Solonetz.

Many objections have been raised to this theory because a number of Solonetz soils examined have contained a rather high content of absorbed calcium, and in some cases of magnesium. This seems to be in conflict with the theory inasmuch as high calcium content is supposed to prevent the deflocculation of the colloidal material of soils. Some hold the theory that magnesium has an effect similar to that of sodium, so that there might be magnesium Solonetz as well as sodium Solonetz. Others believe that the magnesium ion has an effect similar to that of calcium and should, therefore, tend to keep the soil in a more or less granular condition and prevent deflocculation. Up to the present time no one has satisfactorily proved the theory of the formation of Solonetz. It is obvious from the facts available that the soils cannot be strictly defined in chemical terms, especially in regard to the base-exchange complex. It seems obvious that the definition of Solonetz should be a morphological one and should apply to soils having the characteristics described above. It was on this basis that it was originally described, and the morphological characteristics are far more important to the farmer, to the road builder, and to the soil surveyor than slight chemical differences.

Where Solonetz soils occur in imperfectly drained positions it is reasonable to suppose that there may be some variation in the absorbed ions from one season to another. When the water table is high and the weather dry, moderately large quantities of salts will be brought up from the subsoil and deposited in upper horizons. These salts may be rich in sodium or potassium, or they may contain

[14] Although the term Solonetz has long been used in the Union of Soviet Socialist Republics, there appears to be some confusion even there regarding a satisfactory definition for this group of soils. In the usage of the term sometimes a chemical definition is implied, and sometimes the definition appears to rest more specifically on morphological characteristics. It is not surprising, therefore, that some confusion regarding the use of this term has occurred in some of the Western States where Solonetz or Solonetzlike soils occur. There is particular need for further chemical and morphological work on this group of soils occurring in widely scattered localities, in order that chemical character and morphological features may be correlated.

more or less magnesium and calcium. Their content will doubtless have some bearing on the character of the absorption complex. During protracted rainy periods, an abundance of fresh water will tend to remove part of the salts, and it is easy to imagine that some of the salts would be removed more rapidly than others according to their solubilities and according to the strength with which some ions are held by the soil colloids.

Solonetz soils are most abundant in semiarid regions where they receive light accumulations of wind-blown calcareous dust from drier regions. Is it unreasonable to suppose that the calcareous dusts thus accumulated may, in the long run, result in an exchange of ions in Solonetz soil, the sodium being replaced by calcium after a long period of exposure to these conditions? Obviously the whole problem is still very much in a state of flux, and it may be necessary to make many chemical analyses of samples taken from the same spots under different weather conditions and from widely separated areas and under considerably varying climatic conditions before the details of their genesis are discovered.

It is well known that Solonetz soils begin to form where saline soils, high in sodium salts and low in calcium salts, are irrigated and drained. For this reason it is unwise to initiate irrigation projects on saline soils unless there is a high content of lime, gypsum, or other calcium salt in the soil, or unless these are added at the time irrigation is undertaken or are present in the irrigation water.

Dealkalization

When drainage is improved on Solonetz soils dealkalization takes place and the excess sodium carbonate and a great deal of the absorbed sodium is gradually removed. Under these conditions the whitish silty layer, characteristic of the A_2 horizon of Solonetz, becomes gradually thicker. It follows the cracks between the columns to considerable depths, the tops of the columns are gradually bleached, and the collodial clays removed to lower depths. Eventually the upper layers become moderately or strongly acid in reaction, even though parent materials and lower B horizons may remain neutral or alkaline. The soil formed by the dealkalization process might be called dealkalized-claypan soil. It is commonly known among pedologists as Soloth, another word taken directly from the Russian.

Theoretically Soloth soils gradually change to normal soils of the region in which they occur after the normal vegetation has been able to establish itself on them. For instance in a region of Chernozems grasses spread to the Soloth soils, and their roots penetrate deeply to layers rich in lime; and calcium, brought to the upper horizons in the roots and in the leaves of the grass, is deposited in the soil. Calcium combined with the organic matter is in a relatively insoluble form and aids in the aggregation of the fine soil material. In this form it cannot easily be removed in solution or colloidal suspension; thus the light-colored Soloth soil gradually becomes darker and darker until it develops into a true Chernozem. Undoubtedly this process will take a very long time if it actually takes place. In a similar manner, Soloth soils are supposed to change gradually to Chestnut and Brown soils in regions characterized by these types. To what extent theory and fact correspond in these respects is not fully known. The process by which Soloth is formed is sometimes known as solodization.

Transitional Soils

It is not possible to pigeonhole every saline and alkali-affected soil neatly into the groups just discussed. There are many transitional stages between each of them individually and between all of them and the zonal soils with which they are associated. Soils of this general group have a wide variety of common names among farmers. They are known, for instance, as scab spots, slick spots, buffalo wallows, and by many similar names.

MAN *has a passion for classifying everything. There is reason for this; the world is so complex that we could not understand it at all unless we classified like things together. Just as plants, insects, birds, minerals, and thousands of other things are classified, so also are soils. The why and the how of modern soil classification is here explained, and the characteristics and uses of the great groups of soils throughout the world are given.*

Soil Classification

By Mark Baldwin, Charles E. Kellogg, *and* James Thorp [1]

THE soil is a more or less continuous body covering that portion of the land surface of the earth upon which plants grow. That its characteristics vary from place to place probably was recognized by man as soon as agriculture began. The importance of such variations is emphasized in all the early writings dealing with agricultural affairs. This recognition of different kinds of soils and the application of names to them were early steps in soil classification made to satisfy a definite practical need. According to early Chinese records, a classification of soils, made largely on the basis of their color and structure, was developed by the engineer Yu during the reign of the Emperor Yao about 4,000 years ago (*405*).[2]

The soil type as conceived by the modern scientist represents the combined expression of all those forces and factors that, working together, produce the medium in which the plant grows. The fundamental soil types can be described and their capabilities for use can be defined through the interpretation of experimental data and experience. After these types have been defined, knowledge regarding them can be accumulated and classified; and with their distribution shown on maps, this knowledge may be extended to definite areas of land easily and directly.

Since there are a great number of different kinds of soil varying from one another in different degrees of contrast, it is necessary to group them into progressively higher categories in order that the maximum application of our knowledge may be made.

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[1] Mark Baldwin is Senior Soil Scientist, Charles E. Kellogg is Principal Soil Scientist, and James Thorp is Soil Scientist, Soil Survey Division, Bureau of Chemistry and Soils.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

EARLY SYSTEMS OF CLASSIFICATION

The early recognition of soil differences was based on local observations and served local or limited purposes. Many were based on single features of the soil, such as texture or color. These differentiations, while incomplete, were scientifically valid, since they dealt with true soil differences. The rise of geology as a distinct science with field methods and the recognition of the close relationship between soil and its parent material (in most instances the geological formation beneath it) led to a classification based on the composition of the underlying formations, such as the one defined by Fallou (*107*). Other systems of classification,[3] based on features lying outside the soil itself or only partly on soil characteristics, were developed. Some were based on geology strictly, others on physiography, plant ecology,[4] or agricultural quality, or combinations of these. Some of the schemes were fairly complete, in the sense of providing categories[5] and groups for the various features under observation. Thus Richthofen's system (*308*), based for the most part on the geology of the parent material, was sufficiently broad and complete to encompass practically all of the materials of the earth's surface. But it was not a soil classification; the units and the groups were not defined on the basis of soil characteristics, and the nomenclature was geological.

About 1870 a new school of soil science was founded in Russia under the leadership of Dokuchaiev. The scientists of this school recognized that each soil has a definite morphology, or form and structure, which is associated with a particular combination of vegetation, climate, relief, parent material, and age. They stressed the fact that soil is not a geological formation but an independent natural body, and they developed systems of classification in harmony with this new concept. Sibirtsev's Genetical Soil Classification of 1895 (*1*) illustrates in brief form the early trend of Russian soil science toward a genetic soil classification:

Division A. Soils wholly developed or zonal	1. Laterite soils. 2. Aeolian-loess soils. 3. Desert-steppe soils. 4. Chernozem. 5. Gray-forest soils. 6. Podzolized soddy (turfy) soils. 7. Tundra soils.
Division B. Intrazonal soils	8. Alkaline soils. 9. Moor-and-bog soils.
Division C. Immature soils	10. Coarse soils. 11. Alluvial soils.

Here the concept of three main groups of soil, zonal, intrazonal, and azonal (immature) was first presented. The first includes those soils having well-developed soil characteristics that reflect the influ-

[3] For a good discussion of some of the early schemes of soil classification see Afanasiev (*1*).

[4] Plant ecology deals with the mutual relations between plants and their environment, i. e., the relationship of plants to soil, land relief, climate, and other organisms.

[5] The term "category" is used in the sense of a class to which objects of knowledge may be reduced and by which they may be arranged in a system of classification. It is approximately equivalent to "class," but this term has already been appropriated in soil science for the various grades of soil texture, such as loam, sandy loam, and clay loam. It should be clearly distinguished from "group." Similar soils may be placed in a group, the Bellefontaine series; several similar series may be placed in a broader group, the Miami family; and several similar families in a still broader group, the Gray-Brown Podzolic great soil group. Any one particular series, family, or great soil group is a group of soils, but series, family, and great soil group, conceived as separate parts in a system of classification, are categories. Thus Bellefontaine is not a category of soil classification but one particular group of soils in the category "series."

ence of the active factors of soil genesis—climate and vegetation; the second, those soils having more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief, parent material, or age over the normal effect of the climate and vegetation; and the third, those soils without well-developed soil characteristics.

These early Russian investigators were concerned chiefly with the determination of general characteristics and the recognition of soil units that could be given broad geographic expression. They did not define local soil types or groups within the lower categories. As the Russian workers developed their science, the classification came more and more to be based upon soil characteristics and less and less on the environmental factors that produced them.

DEVELOPMENT IN THE UNITED STATES

About 40 years ago soil survey work was instituted in the United States for the purpose of defining and mapping the important soil types in the country. This research was started in the Department of Agriculture and naturally had agronomic purposes. The investigations have continued, in cooperation with the agricultural experiment stations of the States and Territories, up to the present time. Naturally as the science has progressed and as an increasing amount of knowledge has become available, there has been a continued development toward a system based strictly on soil characteristics—less on the environmental and external features and more on the internal soil morphology. From the beginning, in the field classification of soils all features have been taken into consideration that appeared to the scientist to influence the suitability of soils for crops.

> The classification is based mainly upon the physical properties and condition of the soil . . . any chemical feature, such as deposits of marl, or highly calcareous soils, or of highly colored soils is considered as well as character of the native vegetation and the condition of crops. . . . only such conditions as are apparent in the field, such as the texture as determined by the feel and appearance, the depth of soil and subsoil, the amount of gravel, the condition as to drainage, and the native vegetation or known relation to crops, are mapped (*459*).

A system of nomenclature was set up: "Each well-defined area is established as a class and given a local name." The term "class" referred to the texture of the surface soil. The geographical significance of the word "area" is apparent. The unit of classification, called the type elsewhere in the report, had a definite geographical expression. In fact, the choice of a place name as part of the soil-type name, as Roswell sandy loam, is significant and probably implied the concept of restricted distribution for any given type. The scale of the maps (1 inch = 1 mile) was considered ample to allow the delineation of all features of significance. Thus was laid the groundwork for the establishment of soil units, through the accumulation of soil data in the field, and the delineation of the boundaries of the units.

In the same report there is an implied grouping of these soil types, as indicated by the names Roswell loam and Roswell sandy loam, and the development of the concept of the soil series. The basis of the grouping, however, was not clearly conceived. Later the grouping of soil types into soil series had its basis in common geologic origin

(not composition) of the parent material. Thus the Miami soil types were grouped into a single soil series (Miami), because they were "derived from glacial drift."

This grouping of soils on the basis of the geological origin of the parent material from which they were developed led to the grouping of soil types that had few true soil characteristics in common in a single soil series. The result was naturally confusing, and the purpose of classification was defeated. This defect gradually and necessarily was corrected as soil science developed in the United States.

As the work progressed, correlation of soil types between widely separated areas was attempted, and this in itself revealed the necessity of more rigid definitions of the soil units if the work was to have wide value either scientifically or practically. There was a gradual shifting from the geological definition of soil series to one strictly pedological, i. e., one based entirely on soil characteristics, and in 1920 Marbut (*236*), then chief of the United States Soil Survey, definitely listed eight features of the soil profile necessary to the definition of a soil unit. These features were:

(1) Number of horizons in the soil profile.[6]

(2) Color of the various horizons, with special emphasis on the surface one or two.

(3) Texture of the horizons.

(4) Structure of the horizons.

(5) Relative arrangement of the horizons.

(6) Chemical composition of the horizons.

(7) Thickness of the horizons.

(8) Geology of the soil material.

In his paper Marbut further analyzed the data from the soil surveys, which by that time had extended into most parts of the United States, and empirically and logically proceeded to the building up of the broader divisions or categories of soil classification, basing the definition of the groups entirely on soil characteristics. The hundreds of soil types and phases, used as units of mapping, comprised the first or lowest category and included all soils. He was now prepared to group the soils of the United States in broader categories. Accordingly, the multitude of soil types were combined on the basis of their characteristics into two great groups—since named by him the Pedocals and the Pedalfers—to form the highest category. The names were coined by combining the Greek word "pedo" (ground) with an abbreviation of the Latin word "calcis" or "calx" (lime) and with abbreviations of the Latin words "alumen" and "ferrum" (aluminum and iron). Pedocals are distinguished by the accumulation of carbonates of calcium or of calcium and magnesium in all or a part of the soil profile. Pedalfers are distinguished by the absence of carbonate of lime accumulation and usually by an accumulation of iron and aluminum compounds. Marbut, of course, recognized the relationship of these great soil groups to the climatic zones of the country, the first to the subhumid, semiarid, and arid regions, the second to the humid regions. The Pedocals and Pedalfers were subdivided into groups in lower categories on the basis of their character-

[6] Many of the soil terms used are explained in the previous articles, and short definitions are given in the Glossary.

istics. The technical details of the system are set forth in Marbut's last great monograph (*236*). His grouping by categories is summarized in table 1.

Table 1.—*Soil categories*

	Pedalfers (VI-1)	Pedocals (VI-2)
Category VI		
Category V	Soils from mechanically comminuted materials. Soils from siallitic decomposition products. Soils from allitic decomposition products.	Soils from mechanically comminuted materials.
Category IV	Tundra. Podzols. Gray-brown Podzolic soils. Red soils. Yellow soils. Prairie soils Lateritic soils. Laterite soils.	Chernozems. Dark-brown soils. Brown soils. Gray soils. Pedocalic soils of Arctic and tropical regions.
Category III	Groups of mature but related soil series. Swamp soils. Glei soils. Rendzinas. Alluvial soils. Immature soils on slopes. Salty soils. Alkali soils. Peat soils.	Groups of mature but related soil series. Swamp soils. Glei soils. Rendzinas. Alluvial soils. Immature soils on slopes. Salty soils. Alkali soils. Peat soils.
Category II	Soil series.	Soil series.
Category I	Soil units, or types.	Soil units, or types.

In his publication Marbut discussed the "geologic, topographic, physiographic, climatic, and biologic factors" of soil formation, distinguishing between the dynamic (climatic and biologic) factors and the passive factors. He pointed out the geographic significance of these factors and the consequent geographic distribution of the product of their interaction, the soil. The soil proper (the solum) is distinguished from the underlying material (C horizon), and the features which form the differentiating characteristics of soils are mentioned. The categories are defined, and the groups within the categories are described and named.

The desirability of geographic expression in broad zones, correlated with other broad geographic features, was recognized by Marbut in the emphasis he placed upon the so-called mature (zonal) soils, his category IV.

Those kinds of soils which bear the impress of local features of the environment do not find a fully satisfactory place in the scheme, in spite of the profound differences which distinguish them from their associated normal or mature (zonal) soils. They are listed in category III of Marbut's table. In examining such soils it is evident that they are of two general kinds: (1) Those soils which have definitely developed and in many instances strongly developed profile characteristics that reflect a local but dominating feature of the environment or parent material, such as poor drainage or calcareous parent material; (2) those soils which are without definite profile features, owing to youth, characteristics of parent material, or conditions of relief that prevent or inhibit the development of such features.

These two great groups of soils without normally developed profiles are broadly similar to the groups called intrazonal and azonal (or im-

mature) by Sibirtzev in 1895. Glinka (*124*) objected to these names, as well as to the name "zonal," partly because of their geographical connotations. This may be a valid objection to the use of these words in soil classification, but the concepts seem sound, and in the absence of a better nomenclature, these words are used as the names for the groups of the highest category in the system of classification outlined in the following pages.

All the great soil groups listed in Marbut's scheme of classification (categories III and IV) are still recognized, but some changes in names and in the arrangement of categories have been found desirable. The characteristics of the great soil groups are briefly described in the article Formation of Soil and are summarized in table 3 in the Appendix (p. 996). Before proceeding further with a discussion of the higher categories of classification, it will be necessary to define more precisely the lower categories as they are now conceived.

SIMPLE UNITS OF CLASSIFICATION

Three categories are commonly recognized in the classification of soils in the field—(1) series, (2) type, and (3) phase. The grouping of these units in higher categories will be dealt with presently.

The most important of these field units is the soil series—defined as a group of soils having horizons similar as to differentiating characteristics and arrangement in the soil profile and developed from a particular type of parent material. Except for texture, especially of the A horizon, the morphological features of the soil profile, as exhibited in the physical characteristics and thicknesses of the soil horizons, do not vary significantly within a series. These characteristics include especially, structure, color, and texture (except the texture of the A horizon, or surface soil) but not these alone. The content of carbonates and other salts, the reaction (or degree of acidity or alkalinity), and the content of humus are included with the characteristics which determine series.

Each soil in a series is developed from parent material of similar character. Parent material for soil is produced from rocks through the forces of weathering. Similar parent materials may be produced from different geological deposits and in different ways, and unlike parent materials may be produced from the same rocks because of differences in weathering. It is the character of the parent material itself which is important.

It follows that the external characteristics and environmental conditions of the soils within a series will also be similar. Each series has its characteristic range in climate and relief. Ordinarily the more strongly the soil characteristics are developed, the narrower is this range in external features. Except for young soils or those owing their distinctive characteristics to some unusual feature of the parent material, all the soil types within a series have essentially the same climate. It is to be expected, of course, that any differences in climate or relief sufficient to influence the native vegetation significantly would be reflected in the internal characteristics of the soil.

Variations in texture, especially of the A horizon, occur within a series. In former years soils having considerable range in texture throughout the entire profile were sometimes included within a series.

Significant differences in the texture of the B horizon or of the parent material are now considered to be sufficient grounds for recognizing new series.

The soil series are given names taken from place names near the spot where the soil was first defined, such as Miami, Hagerstown, Mohave, Houston, and Fargo. Many of the first series recognized in the United States were given such broad definitions that it became necessary to split them into several series after the soils had been studied more thoroughly. For example, several soil series are now recognized for soils included with the Miami and Carrington as first defined. Of course, the definitions of series cannot be made more closely than the limits of observation and measurement with available field techniques. Such techniques have improved considerably during the past 40 years, and there is promise of their further development.

The soil type is the principal unit used in detailed soil researches. The definition of soil type is identical with that of soil series, except that the texture of the A horizon does not vary significantly. Thus, there may be one or more types within a series, differentiated from one another on the basis of the texture of the surface soil, the upper 6 to 8 inches. Since the greater part of the roots of crop plants are in this upper soil layer and since this part of the soil is directly involved in tillage and fertilization, especial emphasis has been given its texture.

Attention has already been directed to the determination and nomenclature of soil textural classes. The class name of the A horizon (or average of the surface soil to a depth of 6 to 8 inches in soils with weakly developed profiles), such as sand, sandy loam, loam, silt loam, clay loam, or clay, is added to the series name to give the complete name of the soil type. For example, Miami loam and Miami silt loam are two soil types within the Miami series. With the exception of the texture of the surface soil, these two soil types have the same differentiating characteristics, both internal and external. In Bog soils the word peat or muck, whichever is appropriate, is added to the series name to give the complete name of the soil type.

During the time when special emphasis was placed on the geological character of the parent material, soil series were defined in terms that allowed a wide range in soil characteristics, and several types were included within a series. In a few instances the texture of the soil beneath the surface layer was given major emphasis in determining the class name of the soil type before the present concepts were so precisely defined. As the definitions of soil series came to be made more accurately in terms of soil characteristics, there were fewer types within each series. This is to be expected, for it is inconceivable that soils varying greatly in texture would be similar in their other characteristics. Young or otherwise undeveloped soils, such as alluvial soils, may have a considerable range in texture, although by no means the whole range from sand to clay, and still fall within the limits of a particular series. Well-developed soils are now being classified in series having but one or two or, at most, three types. As research continues, the series with only one type will become still more common. Within the range permitted in a soil type there may be small differences in climate—frostiness, for example—of much greater significance to crop plants than to the native plants. Similarly differ-

ences in relief, of little or no importance to the native vegetation, may be significant in the use of the soil when the land is cultivated. Such differences are recognized and mapped as phases of specific types.

A phase of a soil type, then, is defined on the basis of characteristics of the soil, or of the landscape of which the soil is a part, that are of importance in land use but are not differentiating characteristics of the soil profile. The three most important of such characteristics are slope, stoniness, and the degree of accelerated erosion. For example, from the point of view of land use, there are five principal classes of land defined according to slope, as follows:

(1) Nearly level to level land, on which external drainage is poor or slow. From the point of view of slope there is no difficulty in the use of agricultural machinery nor is there likelihood of water erosion.

(2) Gently undulating land, on which external drainage is good but not excessive. All types of ordinary agricultural machinery may be used with ease, and there is little likelihood of serious water erosion.

(3) Gently rolling lands, on which external drainage is good to free but not excessive. Ordinary agricultural machinery may be used, but the heavier types of equipment with difficulty. On soils subject to erosion there is likelihood of water erosion where intertilled crops are planted.

(4) Strongly rolling land, on which agricultural machinery cannot be used. External drainage is free, but sufficient water is available for a good grass cover. Soil erosion is likely to be serious on land planted to cultivated crops.

(5) Steeply sloping and hilly land, on which external drainage is so excessive that good pasture grasses cannot maintain themselves, although trees may be able to do so.

Frequently soil types have no greater range in slope than that allowed within one slope class, but other soil types have a greater range, and in such instances the variations are recognized as phases. The important criteria of these slope classes is not the percentage of slope but their land-use definitions. In itself slope has a limited significance; its importance can be studied and evaluated only in respect to a definite type of soil. For example, some soils with a 5-percent slope erode easily when devoted to clean cultivation, whereas others erode very little under such treatment, even with slopes in excess of 50 percent.[7]

In a similar way phases are defined for differences in stoniness and accelerated erosion (*195*).

HIGHER CATEGORIES OF CLASSIFICATION

The soil series are grouped in higher categories according to their characteristics. Of particular importance to our purpose are the great soil groups. Several of the great soil groups in the United States include hundreds of soil series, differing from one another in important ways because of differences in parent material, relief, and age, but all showing the same general sort of profile. Groups of soils between series and great soil groups, or families of closely related soil series,

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[7] The percentage of slope indicates the number of feet drop for 100 feet in a horizontal plane. A 5-percent slope drops 5 feet in 100, a 50-percent slope 50 feet in 100, and so on.

have been recognized, such as the Miami family, including the Miami, Bellefontaine, Hillsdale, Russell, Fox, and similar soils. On the whole, however, there has been no consistent grouping of all series into strictly defined families intermediate between the soil series and the great soil groups, and based on soil characteristics. This problem may be expected to receive an increasing amount of attention as research proceeds.

The great soil groups, in turn, can be placed in several suborders and three orders—(1) zonal, (2) intrazonal, and (3) azonal.

Except where the continuity of the landscape is interrupted by mountains or large bodies of water, zonal soils occur over large areas, or zones, limited by geographical characteristics. Thus the zonal soils include those great groups having well-developed soil characteristics that reflect the influence of the active factors of soil genesis—climate and living organisms (chiefly vegetation). These characteristics are best developed on the gently undulating (but not perfectly level) upland, with good drainage, from parent material not of extreme texture or chemical composition that has been in place long enough for the biological forces to have expressed their full influence.

The intrazonal soils have more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief or parent material over the normal effect of the climate and vegetation. Any one of these may be associated with two or more zonal groups, but no one with them all.

The azonal soils are without well-developed soil characteristics either because of their youth or because conditions of parent material or relief have prevented the development of definite soil characteristics. Each of them may be found associated with any of the zonal groups.

The arrangement of the principal groups of soils according to these concepts is shown in table 2 in the Appendix (p. 993). The distribution of the more extensive great soil groups in the United States is shown on the map of soil associations at the end of this Yearbook. In only a few instances are there areas of the intrazonal and azonal groups large enough to separate on a small-scale map, but they occur scattered throughout the regions generally occupied by the zonal soils. In those parts of the country where climate and other conditions change greatly within short distances, as in the far Western States, it is not everywhere possible to separate the zonal groups on small-scale maps.

Although the classification must proceed from the small groups upward to the progressively larger groups differentiated by a decreasing number of characteristics, the details of this process are too voluminous to develop here. As there are several thousand individual soil types in the United States, no attempt will be made here to discuss them. The reader will need to consult the separate soil survey reports of particular areas for the description of local soil types.[8]

The scheme of soil classification outlined in table 2 (p. 993) is designed to make it possible to trace any local soil type logically and directly from the lowest to the highest category. It is believed that all soils will fall into one of the three orders, zonal, intrazonal, or azonal, but

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[8] The Soil Survey Division has published more than 1,500 individual maps and reports since its initiation in 1899. The Illinois Agricultural Experiment Station and some other research institutions have published a few additiona soil maps.

it will probably be necessary to add new suborders and great soil groups from time to time as more is learned about the soils of the world.

Geographic Association of Soil Units

In order that the data of soil science may be understood and made available for the solution of practical problems it is necessary that these units of classification be expressed upon maps. The significance of the data shown by such maps is dealt with elsewhere, but their relationship to the problem of classification may be discussed briefly here. The simple units—series, types, and phases—must be shown upon large-scale maps in order that their relationship to one another, to the other local features of the landscape, and to the detailed pattern of human occupancy may be understood. In order that broader relationships may be understood and regional problems attacked, smaller scale maps showing the distribution of soil groups in the higher categories, especially the great soil groups, must be compiled.

Since the soil is the combined product of climate, living organisms, relief, parent material, and age, each different combination of these factors will produce a different soil. If all variations in each factor were measurable, and had measurable influences on the soil, individual soil types would be so numerous that they would occupy points. In a strict sense each soil profile is individual; no two are identical in every detail. Since there can be some range in the environmental factors without producing measurable differences in the soil, each soil type occupies an area rather than a point. The size and shape of individual areas varies greatly in different places.

By constantly enlarging the scale of a map, individual soil types can be shown separately, regardless of the size of the separate areas or the complexity of their pattern. If the scale is fixed at any practical point, however, certain soil types must be grouped together and shown as complexes. As the scale of the map is decreased, the number of such complexes will increase and the number of individual soil types shown will decrease. The definitions of individual complexes are made in terms of the geographic pattern of the soil units making up the complex.

Thus there is an important difference between geographic groups or associations of soils and groups based strictly on soil characteristics in the system of classification. For example, one may find series, types, and phases of Bog soils, Half Bog soils, alluvial soils, and Gray-Brown Podzolic soils in such close association that the individual great soil groups can be shown only on maps of a scale of an inch to the mile or even larger. On any small-scale map it would be impractical to delineate these groups separately. Since they have no common internal characteristics, it is out of the question to place a soil of the Gray-Brown Podzolic great group and one from the great group of Bog soils in the same order or suborder, to take an extreme example. Although they are intimately associated geographically and have the same climate, their profiles and the chemical and physical properties of their horizons are entirely unlike. The fact that an oak tree and a pine tree may be growing side by side is insufficient reason for placing them in the same species or family. The ecologist must recognize and

define particular associations of plants if he wishes to make a generalized or schematic map of vegetation. Similarly an alluvial soil and a Bog soil cannot be classified in the same order, but they can form a part of an association or complex, defined as consisting of certain closely associated soil types with a characteristic pattern of distribution.

The soil complex is used frequently in both detailed and reconnaissance soil mapping and on generalized maps. It is a unit for the purposes of mapping, not a category in soil classification. Two complexes may be quite unlike, yet be composed of the same soil units, in different proportions or in different patterns. The differences between the soil units—series, types, and phases—may be due to differences in any factor responsible for their development. Ordinarily any one complex will lie within the region of one zonal great soil group, and differences between the units composing it will be due to variations in parent material, relief, or age. In mountainous regions, however, where environmental conditions are very complex, the zonal groups of soils may be closely associated in intricate patterns. On any small-scale map, showing the distribution of the zonal great soil groups (Chernozem, Podzol, etc.), soils belonging to intrazonal and azonal groups necessarily are included in the area occupied by a particular group of zonal soils. Thus the great soil groups, as shown on these maps, are, in a sense, complexes of the normal zonal soils and their geographic associates in the intrazonal and azonal groups.

Soils may be grouped in other ways for specific studies. Especially it may be important to group together all the soils in a soil region developed from the same parent material but differing in relief and in degree and character of profile development. Figure 2 (p. 890) shows such a series of profiles, developed from similar parent material. These soils may be expected to occur in association, although not necessarily in equal proportion. They may make an intricate pattern or a simple one. For such a group Milne (*265*) has suggested the appropriate term "catena" (Latin for chain). It may or may not be possible to map the catena, depending upon the uniformity of the factors other than relief. The concept of the catena has proved useful in the United States as a means of facilitating the logical grouping of soil units and for remembering their characteristics and relationships.

NOTES ON NOMENCLATURE[9]

Marbut's terms "Pedocal" and "Pedalfer" have a useful connotation, but they seem to form a better basis for a grouping within the great soil groups than for forming a separate category. It is not feasible, for example, to classify Degraded Chernozem under Pedocal, since it has many of the features of a Pedalfer while still retaining, in some instances, a good part of its carbonate of lime accumulation—one of the principal distinguishing characteristics of the Pedocal. Prairie soils, on the other hand, have no lime accumulation but do have dark-colored, humus-rich A horizons, much like those of the Chernozems, and show but little evidence of podzolization.

Several great soil groups have been renamed in order to eliminate such geographical terms as "southern," "northern," and "eastern." Even if valid for the United States, these terms are inappropriate in Mexico, South America, and other parts of the world. Descriptive terms have been substituted. For example southern brown soils are renamed Reddish Brown soils; northern dark-brown

[9] This section is intended primarily for soil scientists and students of soil science.

soils are now given the European name of Chestnut soils; and southern dark-brown soils are now called Reddish Chestnut soils. Noncalcic Brown soils show several characteristics common to podzolic soils, and, although their profiles are relatively weakly developed, they seem to belong within the outer range of the Pedalfers.

Distinctions among soils of the deserts are not sharp. Characteristics seem to depend largely on vegetation and temperature conditions, and there is much evidence to support the view that age and former relief have been extremely important in determining their character. Brown and Reddish Brown Pedocal soils are indicated as transitional between suborders 1 and 2. Possibly they might comprise another suborder, but it is not certain whether this disposal of them would be justified. They correspond respectively to Marbut's Brown and southern Brown soils.

Chernozem, a literal translation of which is black earth, was formerly described to include not only the nearly black Pedocal soils of the northern Great Plains, but also the dark-brown soils of the southern Great Plains, which have a definitely red or pink tinge, especially in the lower horizons. It is now thought that the latter belong more properly to the southern dark-brown group, for which the new name "Reddish Chestnut soil" is proposed. The subhumid parts of the southern Great Plains, where one would expect to find Chernozem, are underlain by soft marly limestones with black or very dark brown Rendzina soils developed upon them.

The Noncalcic Brown soils seem to owe their characteristics to the wet-dry subhumid climate and to the forest-grass vegetation characteristic of their environment. They were first recognized as a broad group in China under the name Brown soils (*355*), but as this term conflicts with the Brown Pedocal soils, the name "Shantung Brown" soils (*407*) was proposed later. The alternative name of Noncalcic Brown soils has the advantage of eliminating geographic restrictions and at the same time of clearly distinguishing these soils from the Brown Pedocals.

The proposed term "Brown Podzolic" soils covers a great group of soils that have some of the morphological features of immature Podzols. Their recognition as a group of category IV is based upon the wide geographic distribution of their characteristic profile and upon the apparent equilibrium of the well-developed soils with their environment.

Much of Marbut's Southern Prairie belongs to the Rendzina group (as was fully recognized by Marbut himself). Some relatively small areas of true Prairie soils do exist in warm-temperate humid areas of the United States. They have a reddish-brown color and are called Reddish Prairie soils, in conformity with the terminology used for the Pedocals of warm climates. Since much of the Reddish Prairie soil, now recognized in the United States, is developed on red materials, it is not yet known to what extent the color is inherited and to what extent it is developmental. Certainly the Reddish Prairie soils generally contain somewhat less organic matter than the Prairie soils of cooler regions.

It is well-known that there are important areas of Prairie soils in tropical regions, but their characteristics are not yet well enough known to make possible their proper classification.

Table 2 (p. 993) shows an overlap in suborders between the podzolized and lateritic soils. This is because many of the soils whose parent materials are of a lateritic nature show strong morphological and chemical evidences of podzolization. Laterization and podzolization are both active in the humid Tropics. Soils of the Tropics in general, and especially those of the humid and wet-dry Tropics, are not satisfactorily classified. This is more because of a lack of systematized study of data than of a lack of data, although there is still need for a vast amount of field and laboratory work on these soils. For example, we know that there are interrelationships involving Red and Yellow soils, some of which are sticky and plastic, whereas others are granular and friable. Colloids of some have low silica-alumina and silica-sesquioxide ratios, while in others the reverse is true. Marbut proposed the name "Tropical Red Loams" for soils containing a high percentage of friable clays. Although these soils contain much clay, their friable nature gives them a physical character more closely akin to loam. This group corresponds closely to the Reddish-Brown Lateritic soils of the present classification. Yellowish-Brown Lateritic soils have similar physical properties but a decidedly different color. To what extent the chemical properties differ has not yet been determined.

Many soils of the humid wet-dry tropical regions are developed on residual material showing a strong degree of reticulate mottling, apparently caused by

partial segregation of iron compounds from clays. This type of mottling is characteristic of the material originally called Laterite by Buchanan, but it is very common throughout the region of lateritic soils even where chemical characteristics are different from those originally recognized as Laterites. Some of the Red and Yellow soils of the tropical regions are characterized by high organic content in the surface soil, while in others there is but little organic material. Although rocks weather very rapidly in humid tropical regions, the factor of time still remains very important in the development of soils; it is not yet known to what extent this factor influences the characteristics of soils that must be recognized in classification.

Much has been written, especially by European pedologists, concerning Terra Rossa (literally translated as red earth). The term has been widely applied to red soils developed under the warm-temperate Mediterranean type of climate, marked by wet and dry seasons. Many writers have preferred to limit Terra Rossa to soils developed on limestones, while some would have it include any red soil in a Mediterranean climate. According to Blanck's Handbuch der Bodekunde (*38*), Terra Rossas include red soils which vary greatly as to silica-alumina and silica-sesquioxide ratios in the colloidal fraction, and as to lime content. Some analyses show more than 10 percent of calcium oxide, whereas others show only a trace. It is well known that red soils developed on limestones vary in character from strongly podzolized red soils, on the one hand, to true Laterites on the other, and from strongly acid soils to those high in free carbonate of lime. Silica-alumina ratios vary from considerably more than two to much less than one. It seems evident from these facts that Terra Rossa cannot be classified satisfactorily until it has been defined more exactly. At present its only distinction lies in its color.

The terms "halomorphic," "hydromorphic," and "calomorphic" are not entirely satisfactory, since soil genetics rather than soil characteristics are implied. These names were used because they are conveniently short and because certain soil characteristics are associated with high salt content, with wet conditions, and with the presence of absorbed calcium. It would be desirable for these terms to be more descriptive in nature. Broad groups under these suborders more nearly conform to the desirable descriptive name.

The term "Planosol" is being proposed to cover those soils with claypans and cemented hardpans not included with the Solonetz, Ground-Water Podzol, and Ground-Water Laterite. Families of Planosols correspond to associated normal zonal soils. For example, the Grundy family represents the Planosol associated with the Prairie, the Clermont that associated with the Gray-Brown Podzolic, and the Crete that associated with the Chernozem.

Brown Forest soils are here recognized as calomorphic because of their high absorbed calcium. They seem to correspond to Ramann's original Braunerde and are distinguished from the associated Gray-Brown Podzolic soils by lack of evidence of podzolization. They are somewhat leached but have not developed eluvial and illuvial horizons to any appreciable extent. Incomplete evidence indicates that Brown Forest soils may extend well into the Tropics.

Ground-Water Laterites are characterized by hardpans or concretional horizons rich in iron and aluminum compounds and sometimes in manganese. The only family of this group shown in the table is the Tifton, and the Tifton and Caguas series are given as examples. The Caguas series, as mapped in Puerto Rico, includes both Ground-Water Laterite with hardpan and soils with concretionary horizons. These inclusions were made because of scale limitations on the map and not because of a misunderstanding of the character of the soils involved.

Although the azonal soils bear a much stronger imprint of their geological origin than the zonal and intrazonal soils, the fact remains that climatic and vegetation zones have had some influence on their character and development. Azonal soils of desert regions, particularly the Lithosols, are usually alkaline in reaction and often are actually calcareous even where the rock materials do not contain free lime. Lithosols within the Podzol region are likely to be acid in reaction, but this is not always the case and certainly is not true where the parent rocks contain free lime.

Alluvial soils as recognized in the field may or may not have some of the local zonal influences impressed in their characteristics. Their character depends very largely on their source, but local conditions of drainage and vegetation very soon have some influence on their nature after their deposition by streams. Alluvial soils support a larger proportion of the world's population than do any other great soil group. Family separations in alluvial soils depend largely on the char-

acter and source of the silts, sands, and clays of which they are composed and, as with other soils, each takes its name from a well-known and representative soil series.

It will be noticed at once that the nomenclature of the great soil groups involves the use of many color terms; indeed, these terms are the sole ones used in many instances. It is recognized that color is not the most important characteristic of soils. In fact some shade or tint of brown is the most common color of soils throughout the world. Yet the use of these color terms has come to mean more than mere color. For example, the term Chestnut implies not only the color of the A horizon but also the prismatic structure of the B horizon, the accumulation of lime in the substrata, and the grassy vegetation under which the soils develop. This implication comes not from the name itself but from its common use among pedologists during the last few decades for soils with a particular combination of characteristics. Similar statements could be made for other soils of the well-recognized groups. It is hoped and believed that the new names proposed in this classification will come to have equal significance when the characteristics of these newly recognized groups become as well known.

Table 3 gives general information concerning the properties of the soils of the great groups and briefly mentions certain features of their environment and their more important uses.

APPENDIX [10]

Table 2.—*Classification of soils on the basis of their characteristics*

Category VI Order	Category V Suborder	Category IV Great soil groups	Category III Family [1]	Category II Series [1]	Category I Type [1]
Zonal soils: Pedocals	Soils of the cold zone	1. Tundra soils			
	1. Light-colored soils of arid regions	2. Desert soils	Mesa	Mesa	Mesa gravelly loam.
				Chipeta	Chipeta silty clay loam.
		3. Red Desert soils	Mohave	Mohave	Mohave loam.
				Reeves	Reeves fine sandy loam.
		4. Sierozem	Portneuf	Portneuf	Portneuf silt loam.
		5. Brown soils	Joplin	Joplin	Joplin loam.
				Weld	Weld loam.
		6. Reddish Brown soils	Springer	Springer	Springer fine sandy loam.
				White House	White House coarse sandy loam.
	2. Dark-colored soils of the semi-arid, subhumid, and humid grasslands.	7. Chestnut soils	Rosebud	Rosebud	Rosebud fine sandy loam.
				Keith	Keith silt loam.
		8. Reddish Chestnut soils	Amarillo	Amarillo	Amarillo fine sandy loam.
				Abilene	Abilene clay.
		9. Chernozem soils	Barnes	Barnes	Barnes very fine sandy loam.
		10. Prairie soils	Carrington	Carrington	Carrington loam.
				Tama	Tama silt loam.
		11. Reddish Prairie soils	Zaneis	Zaneis	Zaneis very fine sandy loam.
				Renfrow	Renfrow silt loam.
Pedalfers	3. Soils of the forest-grassland transition.	12. Degraded Chernozem soils			
		13. Noncalcic Brown or Shant'ng Brown soils.	Holland	Holland	Holland sandy loam.
				Vista	Vista sandy loam.
				Fallbrook	Fallbrook fine sandy loam.
				Sierra	Sierra coarse sandy loam.
			Placentia	Placentia	Placentia fine sandy loam.
				Ramona	Ramona sandy loam.
	4. Light-colored podzolized soils of the timbered regions.	14. Podzol soils	Weihaiwei	Weihaiwei	Weihaiwei loam.
				Tinghsien	Tinghsien fine sandy loam.
			Kalkaska	Kalkaska	Kalkaska loamy sand.
				Au Train	Au Train loamy sand.
			Rubicon	Rubicon	Rubicon sand.
				Roselawn	Roselawn sand.
			Hermon	Hermon	Hermon loam.
				Colton	Colton loamy sand.
				Becket	Becket loam.

[10] Unfamiliar terms in these tables are defined in the Glossary, p. 1162.

Table 2.—*Classification of soils on the basis of their characteristics*—Continued

Category VI Order		Category V Suborder	Category IV Great soil groups	Category III Family	Category II Series	Category I Type
Zonal soils	Pedalfers	4. Light-colored podzolized soils of the timbered regions (cont'd).	15. Brown Podzolic soils	Gloucester	Gloucester	Gloucester loam.
						Gloucester sandy loam.
					Merrimac	Merrimac sandy loam.
						Merrimac loamy sand.
			16. Gray-Brown Podzolic soils	Miami	Miami	Miami silt loam.
					Fox	Fox silt loam.
					Bellefontaine	Bellefontaine loam.
				Plainfield	Plainfield	Plainfield loamy sand.
					Coloma	Coloma loamy sand.
				Chester	Chester	Chester loam.
					Frederick	Frederick silt loam.
				Porters	Porters	Porters loam.
		5. Lateritic soils of forested warm-temperate and tropical regions.	17. Yellow Podzolic soils	Norfolk	Norfolk	Norfolk sandy loam.
			18. Red Podzolic soils (and Terra Rossa).	Orangeburg	Orangeburg	Orangeburg sandy loam.
					Greenville	Greenville sandy loam.
					Magnolia	Magnolia sandy loam.
					Cecil	Cecil sandy loam.
			19. Yellowish-Brown Lateritic soils	Coto	Coto	Coto clay.
			20. Reddish-Brown Lateritic soils	Bayamón	Bayamón	Bayamón clay.
			21. Laterite soils	Nipe (ferruginous).	Nipe	Nipe clay.
					Rosario	Rosario clay.
		1. Halomorphic (saline and alkali soils of imperfectly drained arid regions and littoral deposits.	1. Solonchak or saline soils	Sage	Sage	Sage clay.
				Lahontan	Lahontan	Lahontan clay loam.
					Fresno	Fresno clay loam.
			2. Solonetz soils	Phillips	Phillips	Phillips loam.
					Rhoades	Rhoades loam.
				Beadle	Beadle	Beadle silt loam.
			3. Soloth soils	Arvada	Arvada	Arvada clay loam.
					Beckton	Beckton silty clay loam.
			4. Wiesenböden (Meadow soils)	Clyde	Clyde	Clyde silty clay loam.
					Webster	Webster silty clay loam.
			5. Alpine Meadow soils	Duncom	Duncom	Duncom silt loam.
			6. Bog soils	Edwards	Edwards	Edwards muck.
				Carlisle	Carlisle	Carlisle muck.
					Pamlico	Pamlico muck.
				Greenwood	Greenwood	Greenwood peat.
					Spaulding	Spaulding peat.

trazonal soils	2. Hydromorphic soils of marshes, swamps, seep areas, and flats.	7. Half Bog soils	Maumee	Maumee	Maumee loam.
				Bergland	Bergland loam.
		8. Planosols	Grundy	Grundy	Grundy silt loam.
				Oswego	Oswego silt loam.
			Clermont	Clermont	Clermont silt loam.
				Vigo	Vigo silt loam.
			Crete	Crete	Crete silt loam.
				Idana	Idana silty clay loam.
		9. Ground-Water Podzol soils	Saugatuck	Saugatuck	Saugatuck loamy sand.
				Allendale	Allendale sandy loam.
			Leon	Leon	Leon sand.
				St. Johns	St. Johns loamy sand.
		10. Ground-Water Laterite soils	Tifton	Tifton	Tifton fine sandy loam.
				Caguas	Caguas clay.
	3. Calomorphic	11. Brown Forest soils (Braunerde)	Brooke	Brooke	Brooke clay loam.
			Burton	Burton	Burton loam.
		12. Rendzina soils	Houston	Houston	Houston clay.
				Soller	Soller clay loam.
				Bell	Bell clay.
			Aguilita	Aguilita	Aguilita clay.
				Diablo	Diablo clay.
zonal soils		1. Lithosols	Underwood	Underwood	Underwood stony loam.
				McCammon	McCammon loam.
			Muskingum	Muskingum	Muskingum stony silt loam.
			Dekalb	Dekalb	Dekalb stony loam.
		2. Alluvial soils	Wabash	Wabash	Wabash clay loam.
				Cass	Cass loam.
			Laurel	Laurel	Laurel fine sandy loam.
				Sarpy	Sarpy very fine sandy loam.
			Sharkey	Sharkey	Sharkey clay.
			Genesee	Genesee	Genesee silt loam.
				Huntington	Huntington silt loam.
			Gila	Gila	Gila very fine sandy loam.
				Pima	Pima silty clay loam.
			Hanford	Hanford	Hanford loam.
				Yolo	Yolo loam.
		3. Sands (dry)			

[1] Families, series, and types listed are intended only as examples to illustrate the system of classification. When all of the soils of the United States (and of the world as a whole) are studied and classified, many more families, a few thousand series, and thousands of local soil types will have to be recognized.

Table 3.—*General characteristics of soils and their environs*

ZONAL

Zonal soils	Profile	Native vegetation	Climate	Natural drainage	Soil-development processes	Productivity (crop plants)	Present use
Tundra	Dark-brown peaty layers over grayish horizons mottled with rust. Substrata of ever-frozen material.	Lichens, moss, flowering plants, and shrubs.	Frigid humid	Poor	Gleization and mechanical mixing.		Pasture and a few short-season crops. Hunting and trapping are associated enterprises.
Desert	Light-gray or light brownish-gray, low in organic matter, closely underlain by calcareous material.	Scattered shrubby desert plants.	Temperate to cool; arid.	Good to imperfect.	Calcification	Medium to high, if irrigated.	Grazing in large units. Intensively farmed in small units where irrigated. Crops specialized in many places.
Red Desert	Light reddish-brown surface soil, brownish-red or red heavier subsoil closely underlain by calcareous material.	Desert plants, mostly shrubs.	Warm-temperate to hot; arid.	do	do	do	Do.
Sierozem	Pale grayish soil grading into calcareous material at a depth of 1 foot or less.	Desert plants, scattered short grass, and scattered brush.	Temperate to cool; arid.	do	do	do	Do.
Brown	Brown soil grading into a whitish calcarerous horizon 1 to 3 feet from surface.	Short-grass and bunch-grass prairie.	Temperate to cool; arid to semiarid.	Good	do	High, if irrigated	Large farms of small grain (if unirrigated). Ranching in large units.
Reddish Brown	Reddish-brown soil grading into red or dull-red heavier subsoil and then into whitish calcareous horizon, either cemented or soft.	Tall bunch grass and shrub growth.	Temperate to hot; arid to semiarid.	do	do	Moderate to high, if irrigated. Not suited to dry farming. Grazing good.	Grazing in large units. Small specialized farms where irrigated.
Chestnut	Dark-brown friable and platy soil over brown prismatic soil with lime accumulation at a depth of 1½ to 4½ feet.	Mixed tall- and short-grass prairie.	Temperate to cool; semiarid.	do	do	Medium. High where irrigated.	Cereal grains, especially wheat and grain sorghums throughout the world. Excellent grazing in large units.

Reddish Chestnut.	Dark reddish-brown cast in surface soil. Heavier and reddish-brown or red sandy clay below. Lime accumulation at a depth of 2 feet or more.	Mixed grasses and shrubs.	Warm-temperate to hot; semiarid.	do	do	do	Cereal grains and cotton. Excellent grazing in large units.
Chernozem	Black or very dark grayish-brown friable soil to a depth ranging up to 3 or 4 feet grading through lighter color to whitish lime accumulation.	Tall- and mixed-grass prairie.	Temperate to cool; subhumid.	do	do	Medium to high. High to very high where irrigated.	Small grains and corn in moderate-sized or large units.
Prairie	Very dark-brown or grayish-brown soil grading through brown to lighter colored parent material at a depth of 2 to 5 feet.	Tall-grass prairie	Temperate to cool-temperate, humid.	do	Calcification with weak podzolization.	High	Medium to small farm units. General farming, with emphasis on corn, hogs, and cattle.
Reddish Prairie	Dark-brown or reddish-brown soil grading through reddish-brown heavier subsoil to parent material. Moderately acid.	Tall- and mixed-grass prairie.	Warm-temperate, humid to subhumid. Possibly some tropical conditions.	do	do	Medium to high	Wheat, oats, corn, cotton, hay, and forage crops.
Degraded Chernozem.	Nearly black A, somewhat bleached grayish A_2, incipient heavy B, and vestiges of lime accumulation in deep layers.	Forest encroaching on tall-grass prairie.	Temperate and cool; subhumid to humid.	do	Calcification followed by podzolization.	Medium to high. Low where strongly degraded.	Agriculture intermediate between Chernozem and Podzol. Of little importance in the United States.
Noncalcic Brown (Shantung Brown).	Brown or light-brown friable soil over pale reddish-brown or dull-red B horizon.	Mostly deciduous forest of thin stand with brush and grasses.	Temperate or warm-temperate; wet-dry, subhumid to semiarid.	do	Weak podzolization and some calcification.	Medium. High were irrigated.	Grazing, dry farming with small grains, specialized irrigated crops including fruits.
Podzol	A few inches of leaf mat and acid humus, a very thin dark gray A_1 horizon, a whitish-gray A_2 a few inches thick, a dark or coffee-brown B_1 horizon, and a yellowish-brown B_2. Strongly acid.	Coniferous, or mixed coniferous and deciduous forest.	Cool-temperate, except in certain places where the climate is temperate; humid.	do	Podzolization	Usually low. Medium under good practices.	Small subsistence farms, including dairying. Wood lots and pasture important.

Table 3.—*General characteristics of soils and their environs*—Continued

ZONAL—Continued

Zonal soils	Profile	Native vegetation	Climate	Natural drainage	Soil-development processes	Productivity (crop plants)	Present use
Brown Podzolic	Leaf mat and acid humus over thin dark-gray A, and thin gray-brown or yellowish-brown A_2 over brown B horizon which is only slightly heavier than surface soil. Solum seldom more than 24 inches thick.	Deciduous or mixed deciduous and coniferous forest.	Cool-temperate; humid. Effective moisture slightly less than in Podzol.	Good	Podzolization	Low to medium. High where heavily fertilized and well managed.	Small subsistence farms, dairying, wood lots, and pasture. Specialized truck crops near large cities are important.
Gray-Brown Podzolic.	Thin leaf litter over mild humus over dark-colored surface soil 2 to 4 inches thick over grayish-brown leached horizon over brown heavy B horizon. Less acid than Podzols.	Mostly deciduous forest with mixture of conifers in places.	Temperate; humid	do	do	Medium. High where well fertilized and managed.	Small farm units with general farming. Wide variety of crops. Some specialization. (Much industrial activity.)
Yellow Podzolic	Thin dark-colored organic covering over pale yellowish-gray leached layer 6 inches to 3 feet thick over heavy yellow B horizon over yellow, red, and gray mottled parent material; acid.	Coniferous or mixed coniferous and deciduous forest.	Warm-temperate to tropical; humid.	Imperfect to good.	Podzolization with some laterization.	Poor. Responsive to good management and fertilization.	Small to medium-sized farm units. Subsistence crops. Cotton, tobacco, peanuts, and some fruit and vegetables. Few livestock. Many wood lots and forested areas.
Red Podzolic	Thin organic layer over yellowish-brown or grayish-brown leached surface soil over deep-red B horizon. Parent material frequently reticulately mottled red, yellow, and gray; acid.	Deciduous forest with some conifers. (With cogonales—burned-over areas covered with cogon, tall coarse grasses.)	do	Good	Podzolization and laterization.	Medium. Responsive to fertilization and good management.	Small to medium-sized farms, with cotton, peanuts, tobacco, and subsistence crops. Much waste land and forests.
Yellowish-Brown Lateritic.	Brown friable clays and clay loams over yellowish-brown heavy but friable clays. Acid to neutral.	Evergreen and deciduous broad-leaved trees. Tropical selva. (Some cogonales.)	Tropical; wet-dry. High to moderate rainfall.	Good externally. Good or excessive internally.	Laterization and some podzolization.	Low. Medium with irrigation and fertilization.	Small farm units, with subsistence and some specialized crops. Some forests.

Reddish Brown Lateritic.	Reddish-brown or dark reddish-brown friable granular clayey soil over deep-red friable and granular clay. Deep substrata reticulately mottled in places.	Tropical rain forest to edge of savannah. (Some cogonales.)	Tropical; wet-dry. Moderately high rainfall.	Good externally and internally.	Laterization with little or no podzolization.	Low to medium. Medium to high where fertilized and irrigated.	Small farm units with subsistence crops. Plantations of citrus, pineapple, sugarcane, etc. Some forest.
Laterite	Red-brown surface soil. Red deep B horizon. Red or reticulately mottled parent material. Very deeply weathered.	Tropical selva and savannah vegetation. (Some cogonales.)	Tropical; wet-dry. High to moderate rainfall.	Good externally. Good or excessive internally.	Laterization and a little podzolization.	Low. Medium to high with heavy irrigation and fertilization.	Small farm units with wide variety of subsistence crops. Some specialization on plantations. Large areas of waste land and forest. Mined for iron and aluminum in places.

INTRAZONAL

Intrazonal soils	Profile	Native vegetation	Climate	Factors responsible for development	Natural drainage	Soil-development processes	Productivity (crop plants)	Present use
Solonchak	Gray thin salty crust on surface, fine granular mulch just below, and grayish friable salty soil below. Salts may be centrated above or below.	Sparse growth of halophytic grasses, shrubs, and some trees.	Usually subhumid to arid. May be hot or cool.	Poor drainage with evaporation of capillary water. Salty accumulations.	Poor or imperfect.	Salinization	Very low except where washed free of salts.	Some grazing. Much waste land. Used for producing salt and saltpeter in places.
Solonetz	Very thin to a few inches of friable surface soil underlain by dark, hard columnar layer, usually highly alkaline.	Halophytic plants and thin stand of others.	do	Improved drainage of a sodium Solonchak.	Imperfect	Solonization (desalinization and alkalization).	Low (medium where reclaimed).	Same use as associated normal soils.
Soloth	Thin grayish - brown horizon of friable soil over whitish leached horizon underlain by dark-brown heavy horizon.	Mixed prairie or shrub.	Usually subhumid to semiarid. May be hot or cold.	Improved drainage and leaching of Solonetz.	Imperfect to good.	Solodization (dealkalization).	Low to medium.	Do.
Wiesenböden (Meadow).	Dark-brown or black soil grading, at a depth of 1 or 2 feet, into grayish and rust-mottled soil.	Grasses and sedges.	Cool to warm; humid to subhumid.	Poor drainage	Poor	Gleization and some calcification.	Generally high or very high when drained.	Used in connection with associated normal soils. Drained areas similar to Prairie.

Tabe 3.—*General characteristics of soils and their environs*—Continued

INTRAZONAL—Continued

Intrazonal soils	Profile	Native vegetation	Climate	Factors responsible for development	Natural drainage	Soil-development processes	Productivity (crop plants)	Present use
Alpine Meadow.	Dark-brown soil grading, at a depth of 1 or 2 feet, into grayish and rust soil, streaked and mottled.	Grasses, sedges, and flowering plants.	Cool-temperate to frigid (alpine).	Poor drainage and cold climate.	Poor	Gleization ond some calcification.	Yields limited by cool climate.	Mostly summer pasture.
Bog	Brown, dark-brown, or black peat or muck over brown peaty material.	Swamp forest or sedges and grasses.	Cool to tropical; generally humid.	Poor drainage. Water-covered much of the time.	Very poor	Gleization	Low or medium. High in some places where drained.	Special crops when drained. Undrained areas in forest - swamp or marsh plants.
Half Bog	Dark-brown or black peaty material over grayish and rust-mottled mineral soil.	do	do	do	do	do	Medium to high when drained. Some low.	Used in connection with normal soils for pasture or forest, where undrained, and for special crops where drained.
Planosols	Strongly leached surface soils over compact or cemented claypan or hardpan. Some have normal A and B horizons above the claypan or hardpan—a secondary profile.	Grass or forest	Cool to tropical; humid to subhumid.	Flat relief, imperfect drainage, and great age.	Imperfect or poor.	Podzolization, gleization. Also laterization in tropics.	Medium to low	Crops, pasture, and forest trees, varying with regions in which they occur.
Ground-Water Podzols.	Organic mat over very thin acid humus, over whitish-gray leached layer up to 2 or 3 feet thick, over brown or very dark-brown cemented hardpan or ortstein. Grayish deep substrata.	Forest of various types.	Cool to tropical; humid.	Imperfect drainage and usually sandy material.	do	Podzolization	Low to medium in cool areas. Low in warm areas.	Forest. Some land planted to regional crops and pasture grasses.

Ground-water Laterites.	Gray or gray-brown surface layer over leached yellowish-gray A_2 over thick reticulately mottled cemented hardpan at a depth of 1 foot or more. Hardpan up to several feet thick. Laterite parent material. Concretions throughout.	Tropical forest	Hot and humid; wet and dry seasons.	Poor drainage and considerable or great age.	do	Podzolization and laterization.	Low to medium	Subsistence crops, sugarcane, and forest trees.
Brown Forest (Braunerde).	Very dark brown friable surface soil grading through lighter colored soil to parent material. Little illuviation. High absorbed calcium.	Forest, usually broad-leaved.	Cool-temperate to warm-temperate; humid.	High calcium colloids and youth.	Good	Calcification with very little podzolization.	High	Subsistence and regional crops, pasture and forest.
Rendzina	Dark grayish-brown to black granular soil underlain by gray or yellowish, usually soft, calcareous material.	Usually grassy. Some broad-leaved forest.	Cool to hot; humid to semiarid.	High content of available lime carbonate in parent material.	do	Calcification	do	Regional and special crops. Pasture grasses.

AZONAL

Azonal areas	Profile	Vegetation	Climate	Drainage	Soil-development processes	Productivity and present use
Lithosols	Thin, stony surface soils—little or no illuviation. Stony parent materials.	Depends on climate.	All climates. Most characteristic of deserts; least so of humid Tropics.	A wide range, mostly good to excessive.	Those characteristic of the region. Little effect has been made.	Forestry, grazing, barren. Some agriculture on limited areas. Low productivity.
Alluvial soils	Little profile development. Some organic matter accumulated. Stratified.	do	All climates except extremely frigid ones.	A wide range, mostly poor to good.	do	Practically all crops of world represented. Yields vary from very high to very low. Large proportion of world's population supported by production from alluvial soils. Both subsistence farms and large plantations on these soils.
Sands, dry	Essentially no profile. Loose sands.	Scanty grass or scrubby forest. Much of land has no vegetation.	Humid to arid, temperate to hot.	Excessive	do	Very seldom used except for grazing.

A GOOD DEAL *of the scientist's knowledge of soils is summed up graphically and concretely in soil maps. With their accompanying descriptions, soil maps are invaluable guides to efficient use of the soil and to intelligent planning. This article tells how soil maps are made, what information they contain, and what they may be used for.*

Soil Maps and Their Use

By J. Kenneth Ableiter[1]

WHAT does a soil map show, how is it made, and what use is it? Those are questions often asked by farmers when they see a soil surveyor busily sketching at a table set up in a field or by a roadside.

A soil map is primarily a representation on paper of the distribution of the mappable soil units—predominantly the soil type—of a given landscape, although selected cultural and other physical features are shown. These units—the soil type, the phase, the complex, and the miscellaneous land type—have been described in the article Soil Classification. The character of the individual unit is based upon observable internal and external characteristics of the soil. The color, structure, texture, and consistence of the separate horizons of the soil profile are examples of internal characteristics, while the form and steepness of slope and degree of stoniness are examples of external characteristics. These are illustrated by various photographs in Soils of the United States (p. 1019). These characteristics of the profile and landscape have or may have significance in the growth of crops, grasses, and trees.

In areas where the characteristics of the soil profile are very similar, differences in relief commonly serve as a basis for the recognition of mappable units. In other areas with similar relief the presence or absence of a 4-inch layer of intractable clay at a depth of 12 inches may be a basis for the differentiation of soil areas. On the other hand, the presence or absence of a 4-inch layer of intractable clay at a depth of 6 feet, the effects of which are not evident in the upper portions of the profile, cannot be taken generally as a mappable characteristic under present conditions of mapping. This may not be true always.

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The selection of suitable soils for deeply rooted crops such as orchard trees or alfalfa may possibly justify such detailed mapping in specific areas today. Similarly, detailed differences in the phosphorus content of surface soils are not mappable and cannot be made a basis for distinguishing soil units in the field. This does not mean that certain crops in individual fields do not justify the examination of the soil in great detail. Thus, samples from each square foot could be analyzed in the laboratory and the results shown on a map. Such an undertaking involves relatively enormous costs; hence it has been rarely justified.

Only in a limited number of instances can chemical differences such as reaction (degree of acidity or alkalinity) be used directly as a primary basis for the recognition of mapping units. Even then, accompanying physical differences usually are to be observed. Thus a difference in reaction of the surface and subsoils is the principal distinction between the Chagrin and Tioga soils of the bottom lands of New York.

It must not be thought, however, that the present units of the soil map have little meaning in relation to the chemical constitution of the soil. Fortunately, as a result of investigations in the laboratory and and on experimental plots, correlations can be made between the observable features of the soil and its chemical character and productive ability. Again, correlations can be made from the experience of farmers. A part of the work of the future is to investigate more completely the chemical and nutritional properties of the mappable soil types in order to determine which characteristics are merely accidental and which express the inherent character of the soil.

The actual practices of farm management of individual farms, fields, or soil types contribute greatly to what may be called the accidental presence or absence of a particular plant nutrient in the surface soil. This effect is not to be confused with the more stable chemical constitution of the soil as developed from the parent material under the conditions of the natural environment. Present conditions of fertility (referring to the supply of plant nutrients) of any land managed by man depend upon the relative influences of these two factors of inherent fertility and management. It must be added, however, that the complex of all of the characteristics of the natural soil enters into the determination of what the results of man's techniques will be.

The soil map, by delineating those soil areas that possess similar levels of inherent fertility and similar physical characteristics which together influence soil productivity, can be used by the farmer to guide him in the use of specific recommended practices—practices developed by the investigation and experience of others on similar soils. For example, it may have been found experimentally or through the experience of farmers that certain soil types can be cropped to corn safely only once in 4 years; that other types may grow corn safely in 3 years out of 4, provided the nitrogen supply is maintained by a green-manure crop; and that other areas cannot be recommended for cultivation under any feasible system of management. Other soils may be known to be naturally low in potash, or to respond to phosphates, or to be benefited by fall plowing. In this way the soil map serves to bring to the farmers the findings of experimental research.

Since each soil type or mapping unit expresses certain characteristics of the landscape, the soil map, by showing their distribution, serves to give a picture of the landscape as a whole. Drainage patterns with their permanent and intermittent streams, smooth tablelands, ridgelike divides, rolling hills, and steep slopes that break abruptly into valleys and bottom lands may be seen. These physical features are located in reference to such cultural features as cities, cross-road stores, highways, farmhouses, railroads, and section corners.

THE MAKING OF A SOIL MAP

The work of making a soil map involves preliminary work in the field, the actual mapping, and subsequent work prior to the publication of the map.

The preliminary work consists in the determination of the character of the soil types and the other soil units that occur in the county or area to be mapped. Detailed knowledge of the internal and external soil features of the area is necessary and can be acquired only through the complete and careful observation of the different types of soil profiles as developed under the various conditions of relief, drainage, vegetation, and parent material.

The observations of soil conditions are best made by exposing the soil profiles by means of a series of excavations upon selected sites. The significance of each soil condition to the agriculture and land utilization of the area must also be studied. All of this work leads up to the determination of what soil types, phases, complexes, or miscellaneous land types are mappable and can be shown without exaggeration on the scale of map that is planned for the area. Following the determination of the soil units, written descriptions of each are prepared and incorporated with general instructions on mapping into what is known as the descriptive legend.

After copies of the descriptive legend are in the hands of each man of the mapping party, the mapping of soils may begin, provided a suitable base map is available. In the past, frequent use has been made especially of the topographic quadrangles of the United States Geological Survey, the maps of the United States Coast and Geodetic Survey, and those of the United States Army engineers. With the advent of aerial photography, photographs are taken into the field and on them or on specially prepared transparent covers are shown the location of the soil boundaries, streams, houses, and other features.

Lacking an accurate base map (fig. 1), the soil surveyor prepares one by measuring distances on the ground and plotting them to scale on the field sheet. The usual scale is 2 inches to 1 mile. Aerial photography is now rapidly doing away with the necessity for making base maps by the older methods of the surveyor. These methods are described in detail in the Soil Survey Manual (*195*).[2]

After the completion of the base map, actual soil mapping, which consists in the placing of soil boundaries, may begin. In this process, the mapper does three distinct things. (1) He keeps his location, (2) identifies the soil units of the landscape, and (3) sketches their pattern of distribution to scale on the map. The proper identification of the soil types and other soil units requires constant observation of the

[2] Italic numbers in parentheses refer to Literature Cited p. 1181.

landscape and sufficient examination of soil profiles to enable the mapper always to know the character of the soil before him. In observing the association of soil characteristics with landscape features, the mapper learns to visualize the extent of each soil unit and the pattern of its distribution. External features of the landscape, such as relief and native vegetation, come to be recognized as indicators of the local soil types. Experience and judgment are needed to interpret the landscape in terms of the proper soil units with their corresponding agricultural significance.

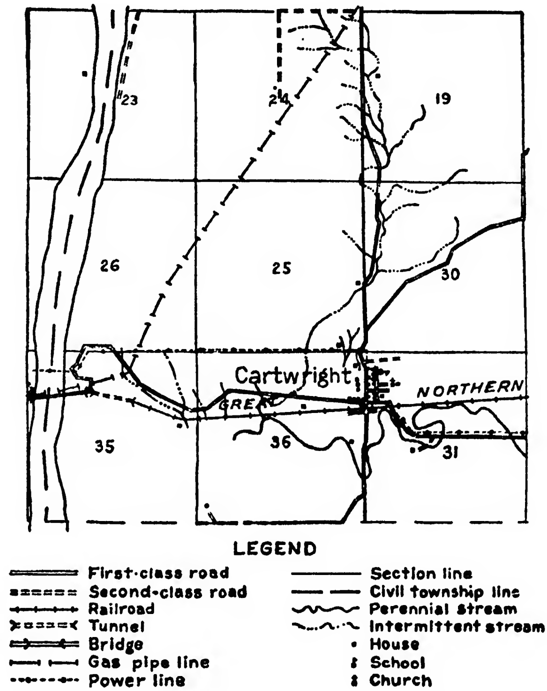


Figure 1.—A fieldman's base map, showing two classes of highways, a railroad, a small village, farmhouses, a church, a gas pipe line, a power line, a large river, perennial stream, intermittent drains, section lines, and township line (middle of river channel).

After the visualization of the extent of the soil units by the mapper, he proceeds to sketch their boundaries on the soil map. The classification of a soil unit and its boundaries must coincide with actual conditions without omission of important characteristics or exaggeration of minor details. A finished map is not a crude crowding together of areas but a representation of a natural landscape. Not all boundaries have equal significance. One may represent a sharp and distinct break in soils and topographic features, such as the line between a rocky slope and a nonstony flat. Other boundaries may represent transitional conditions, such as the line separating a loam from a silt loam on a long gentle slope.

Figure 2, *A* and *B*, and figure 3 suggest the relation between the landscape and the completed field map. Mapping is the technique of representing the dynamic landscape in abstract form on the flat surface of paper. The two figures illustrate the stages whereby the living landscape is sketched on the soil map.

The first picture (fig. 2, *A*) shows principally a farmstead located on a smooth alluvial plain. Across the river are seen cleared terraces and slopes. Most of the hilly land is timbered. The second picture (fig. 2, *B*), the perspective, illustrates the sort of mental picture the mapper formulates when viewing the landscape. The numerals indicate the

Figure 2.—The relation of the landscape to the soil map: *A*, Landscape scene along the French Broad River in east Tennessee; *B*, the same landscape drawn in perspective to illustrate the mental picture carried by the mapper.
(Courtesy of C. C. Nikiforoff.)

types of soils. The third picture (fig. 3) is taken from the field sheet of the map for this particular landscape. The photograph is taken from the extreme lower right-hand corner and does not cover the entire map. The farmhouse can be seen to the left of the road. The apparently smooth bottom land is seen to be occupied by three soils, numbered 34B, 139, and 149. The steepest hills to the left are mapped 15E. The published soil map will be in color.

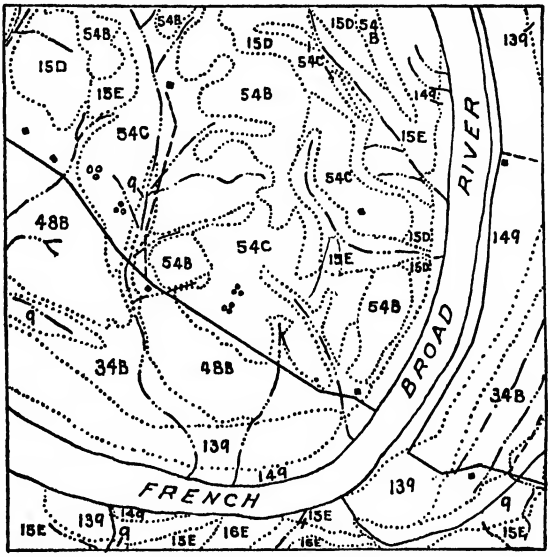


FIGURE 3.—Reproduction of map of area shown in figure 2 as drawn in the field by the soil surveyor. The camera for figure 2, *A*, was set up in the extreme lower right-hand corner on the area of 15E.

TYPES OF SOIL MAPS

The three general types of soil maps according to the refinement of the mapping are the reconnaissance, the detailed, and the detailed-reconnaissance. In the reconnaissance survey the soil boundaries are plotted from observations made at various distances apart, and not throughout their course as is done in the making of the detailed map. The detailed-reconnaissance map is a composite wherein a part of the map is detailed and a part reconnaissance. Recent soil maps show a greatly increased number of soil types as compared to the early maps of 30 or more years ago. This is a result of the rapid advances made in the classification of soils. Fieldmen have been enabled to observe and interpret more clearly less apparent differences in soils.

Most of the soil maps of the Soil Survey Division are published on a scale of 1 inch to the mile. Until a few years ago this was also the scale of mapping in the field. Most of the current field mapping is now on a scale of 2 to 4 inches to the mile. Larger scales are employed in the field for particular areas, such as demonstration farms. In areas where erosion control and land use are of immediate concern, the scale of the field mapping is commonly 4 inches to the mile. By the use of the larger scales the mapper is enabled to include the more transitory data that are the result of economic and social influences, such as the location of crops, the use of the land, and the effects of management practices upon production in addition to the relatively permanent data of the physical landscape. This detailed information may be excluded later from the published map on the 1-inch-to-a-mile scale.

The published county maps are shown in a color pattern designed to bring out the identity of each of the soil areas. More generalized soil maps are shown frequently by black and white patterns. The field sheets carry only symbols (numerals and letters) to designate each soil unit.

Although a legend must accompany each published map in order to list the proper soil name for each soil type or other unit, the utility of the map is limited without a written report. Little meaning is given, for example, by the legend when it is indicated that a pink-colored area marked OL is known as Onaway loam. There is need to describe the soil characteristics and to explain the significance of the soil for the growing of crop plants, grasses, or trees.

In the future the number of colors on the soil map is to be reduced. Related soils of similar characteristics, though distinguished by boundaries and symbols, will have the same color. It is believed this will be a distinct aid in more rapid interpretation of the soil map.

Reading the Soil Map

Figure 4 shows a portion of a detailed soil map for a county in the driftless area of southwestern Wisconsin. Here it is in black and white. The original would be in color and would show each of the soil types by a separate color division, much easier to distinguish than the lettered and cross-hatched areas. A brief examination of the map presents certain information about the nature of the landscape. For example, the distribution of the soil types is seen to be closely related to the drainage pattern, which is of the branching (dendritic) type. The narrow and somewhat tortuous ridges indicate that they are the last bulwarks against a cycle of erosion passing into maturity. Around the head of each drainageway is seen a belt of steep or rough broken land which separates the bottom land from the ridge tops. The distribution of farmhouses and roads on the ridges and in the valleys suggests that most of these slopes are too steep to be traveled. Furthermore, over half of the county appears to consist of the steep phases of the Clinton and Dubuque silt loams and the rough broken land.

Further reference to the legend indicates that the majority of soil types are silt loams, while more study of the map and legend shows that the Boone fine sandy loam and Boone loam are mapped next to the Ray soils of the valley floor in Torgeson and Joy Hollows. This rather specific occurrence of the more sandy textures in a country dominated by silt loams evidences a difference in the parent material of the respective soils and may interest the geological student.

Although the map and legend shown in figure 4 may answer every question as to the distribution of soil types, it is obvious that little information has been gained about the significance of these soil types for agriculture. It may be inferred that much of the area is unsuited for cropping because of steepness of slope, but no inkling is afforded as to the distinctions between Tama silt loam and Clinton silt loam or the reasons for the recognition of the steep phase of Dubuque silt loam as a separate map unit from the steep phase of the Clinton silt loam.

The reader who is interested in this area, therefore, is forced to turn to the soil descriptions of the report for a knowledge of soil characteristics, as well as for information concerning the present use of the land

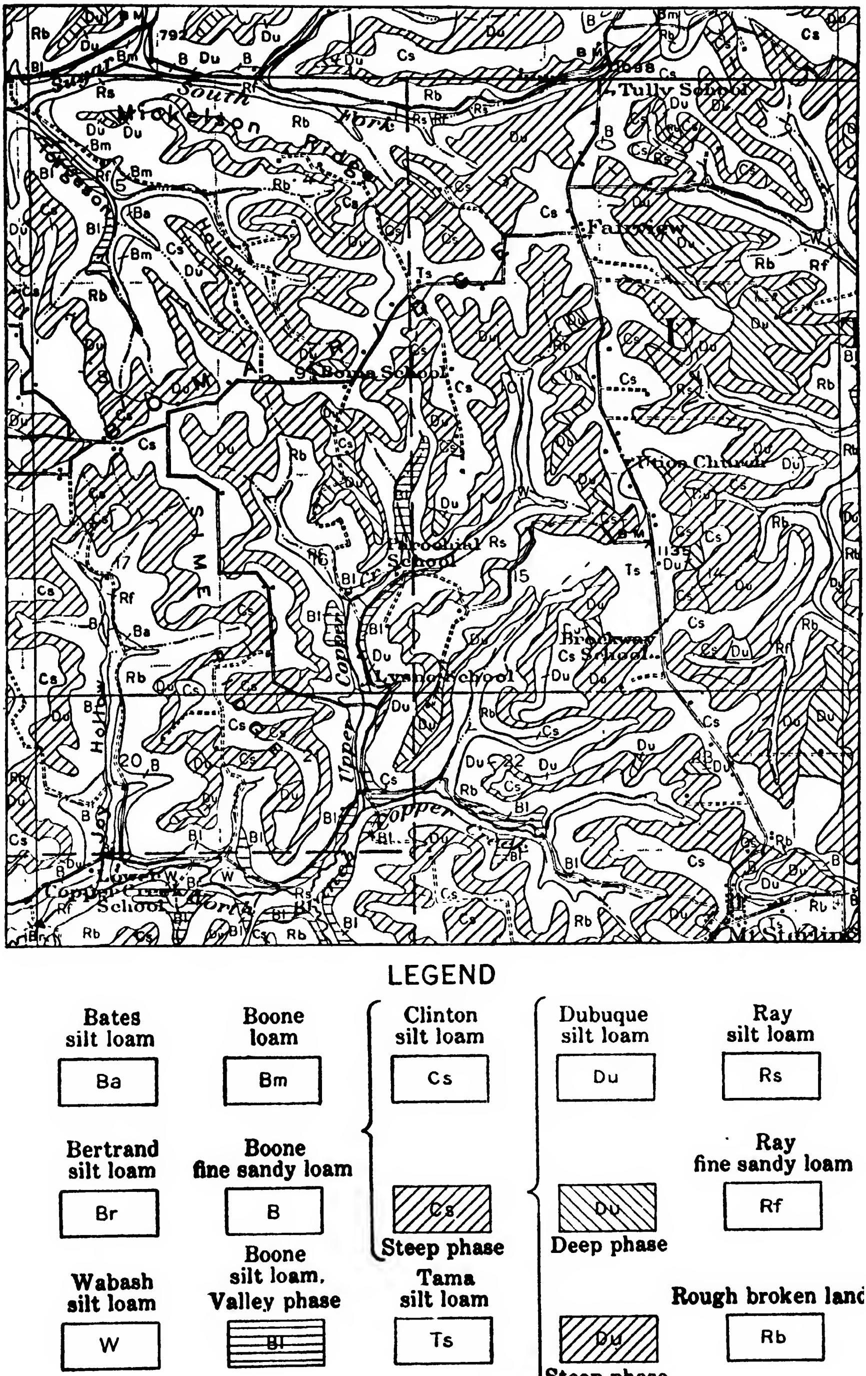


FIGURE 4.—Reproduction in black and white of a portion of a published soil map (Crawford County, Wis.) illustrating the type of information that is carried by a soil map in respect to the distribution and location of soils and other natural and cultural features.

and recommendations for its management. With some idea of the relationships among the soil units of the map and their significance for agriculture, he can visualize much more effectively the landscape pictured by the map. Without the report the map is limited in its usefulness for agriculture, although it may serve as an accurate road map, drainage map, railroad map, or population map.

FURTHER USES OF THE SOIL MAP

Broadly speaking, any individual or agency interested in either the specific character of individual land units or in the broader aspects of regional land use and land planning holds the soil maps and reports of the Soil Survey Division to be indispensable. The use of the soil survey map and report in determining the suitability of certain lands for irrigation or drainage projects illustrates the type of work dependent upon the information of the soil map.

Again, local authorities, county agents, and others working in a locality can use a soil map to prepare a series of maps bringing out different characteristics of the soils of a county. Thus the soil units could be drawn upon a drainage map and classified as (1) excessively drained (droughty) soils; (2) well-drained; (3) imperfectly drained; and (4) poorly drained. Instead of a map of, say, 50 colors, one of 4 would result. Similar differentiations and combinations might be made as to conditions of texture, structure, color, stoniness, relief, or erosion. A map might show the distribution of soils with different lime requirements. Other maps might show the suitability of soils for corn, alfalfa, or tobacco. A general classification as to suggested land use for short rotations, long rotations, permanent pastures, and forests might be prepared. No two maps would agree in outline of boundaries, although certain characteristics would appear to be associated with each other. The fact that many types of maps may be prepared from a soil map illustrates the complex character of the soil unit.

Another illustration of the use of the soil map comes from the Tennessee Valley. With the encouragement of the cooperative agricultural program in the valley, the farmers of various communities have established demonstration farms (fig. 5) where the benefits from rotations and phosphate are observed. Each farm is mapped in detail in

FIGURE 5.—View of demonstration farm in Tennessee. The farm and farm buildings occupy the foreground and left-hand side of the picture.

order to establish the experimental work on specific soil and land types (fig. 6). The mapping is done in even greater detail than the detailed soil map in order to bring out every small variation of the

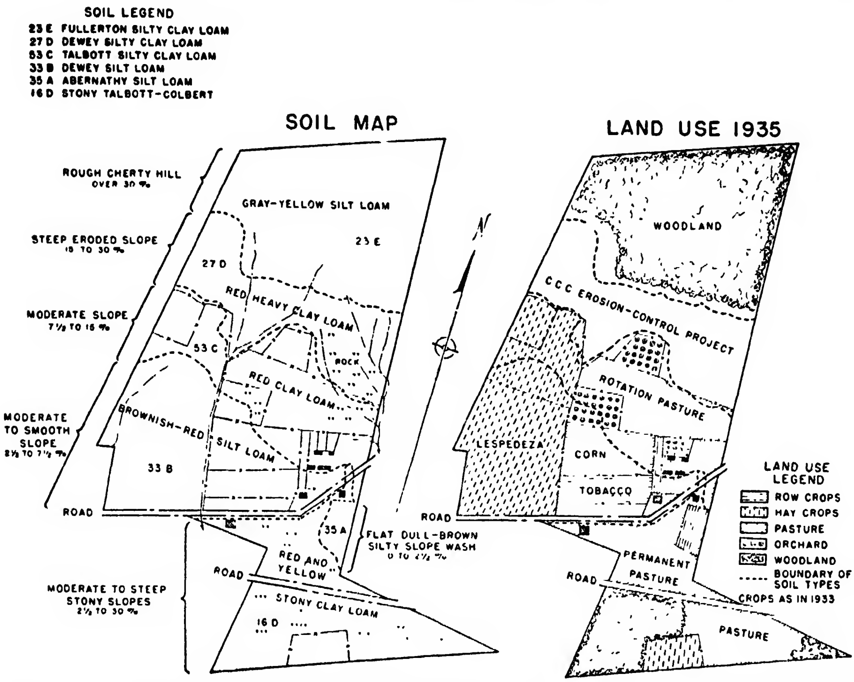


FIGURE 6.—Reproduction of soil map and land-use map of the same farm shown in figure 5. The field in the immediate foreground of the picture is the rectangular area at the bottom of the maps. (Courtesy of the Agricultural Division, Tennessee Valley Authority.)

physical landscape. The results from these demonstration farms are then applied on the individual farms throughout the county according to the soil types found on the detailed soil map.

Productivity Ratings

A feature that has received considerable attention during the past 5 years within and without the Department and the State experiment stations is the preparation of soil-productivity ratings. The Soil Survey Division has adopted the policy that such ratings are to be included in the soil survey reports, and where possible the current reports of counties and areas in various parts of the country carry these ratings. This policy is a recognition of the fact that the scientific classification of soils should lead to an understanding of the practical aspects of soil productivity and land utilization. Morphological distinctions have physical and chemical attributes significant for the growth of crop plants, grasses, and trees.

Factors controlling the inherent productivity of the soil vary from place to place. Over broad areas, differences in climate may be of

extreme importance. Locally, however, differences in productivity are associated usually with differences in topography, drainage, or parent-soil material. For example, the degree of stoniness may be the most important factor (fig. 7), as in areas of the northern Lake States. Again, the depth of bedrock or the calcium content of the parent material may be the dominant factor influencing local, though

FIGURE 7.—Were it not for its external characteristic of stoniness, this soil would be suited for cultivated crops.

marked, differences of productivity. This is true in parts of the great Appalachian Valley. Southwestern Iowa is an example of an area in which slope differences dominate soil productivity. It should be emphasized that soil productivity and soil fertility are not the same. Fertility refers only to the content of plant nutrients. Because of imperfect drainage, for example, a soil of high fertility may be much less productive than one of lower fertility.

The productivity-rating tables, one of which is reproduced here as table 1, bring out both the local and the broader regional differences among the soils by establishing standard yields as points of reference. The standard yield (100) for each specific crop represents approximately the average yield obtained without such amendments as fertilizers and lime on the best soil of the region in which the crop is principally grown. Thus, the exceptional and not extensive soil types that are especially well adapted to a particular crop receive indexes above 100. If the index were not on this basis, it would be necessary

to establish a standard so high that large areas known for their production of a crop might receive relatively low ratings. For example, the standard for permanent pasture is taken as the carrying capacity on the better bottom lands (Wabash) of the Corn Belt of eastern Iowa rather than the much greater carrying capacity of the small strip of country along the Pacific coast in Washington and Oregon. The standards refer to the inherent ability of the soil to produce the particular crop under the common practices of tillage without the use of amendments.

Soil productivity is a result of management as well as inherent qualities, although it must be remembered that these qualities determine the capability of a soil to respond to management. Thus, crop ratings for the production under current practices are given in the table, and in addition, wherever possible, ratings for the inherent ability of the soil to produce the crops without the use of amendments. If the production under current practices through the use of amendments is greater than the standard index of inherent productivity, the appropriate index above 100 is assigned. In this way, responses to management are recorded.

The crop-productivity indexes are obtained from both yield records and the opinions of men experienced with the particular soils in question. Substantiating data in many instances are not readily available. This is easily understood when it is realized that a majority of fields do not coincide with the soil units of the map.

In addition to the ratings for specific crops, general productivity ratings or grades are assigned to each soil unit on the basis of the suitability of the soil to produce the crops of the region. These grades range from 1 to 10 and are based upon the average of the crop-productivity indexes weighted on a percentage basis according to the relative importance of the individual crops. Thus, soils with a weighted average of crop-productivity indexes between 90 and 100 are grouped in grade 1; those between 80 and 90 in grade 2, etc. Further explanation of this procedure is in the text of the current soil survey reports carrying these tables. It is recognized that this rating does not necessarily give a true picture of the economic worth of these soils. A certain soil may possess unique characteristics that make it well-adapted to a crop of high value but of limited acreage, and at the same time may be totally unsuited for the general crops of the region.

Although the inclusion of productivity ratings in the soil report involves questions as to methods and values, the attempt illustrates another effort to improve the soil map and report. Similarly, efforts are being made to show greater detail in the mapping of conditions of soil, slope, stoniness, and erosion, and to show the separations on the map and in the report in such groupings that the agricultural relationships and significances of the units will be emphasized.

Table 1.—*Productivity ratings of soils in Wyoming County, N. Y.*

Soil	Crop-productivity index [1] for—														Productivity grade according to—		Principal crops or type of farming
	Corn silage	Wheat (winter)	Oats	Buckwheat	Tame-grass hay [2]	Red clover	Alsike clover	Alfalfa	Field beans	Potatoes	Vegetables [3]	Vegetables [4]	Tree fruits [2]	Permanent pasture	Inherent productivity [5]	Current practices [6]	
Genesee silt loam, high-bottom phase	90	70	80	90	90	80	------	60	70	50	40	80	50	100	3	3	General (corn, wheat, hay).
Chagrin silt loam, high-bottom phase	90	70	80	90	90	70	------	50	70	60	40	80	50	90	3	3	Do.
Honeoye silt loam, deep phase [7]	70(100)	80(100)	80(100)	100	80(100)	80(100)	------	70	60(90)	50(60)	30	70	60(80)	90	3	1	General, alfalfa, beans.
Lansing silt loam [7]	70(100)	80(100)	80(100)	100	70(100)	80(100)	------	70	40(80)	60(70)	30	70	60(80)	90	3	1	General.
Ontario loam, gray-subsoil phase [7]	60(90)	70(90)	70(90)	90	70(100)	80(100)	------	70	50(70)	60(70)	30	70	60(80)	80	4	2	Do.
Genesee silt loam:																	
Protected	100	70	70	90	100	100	------	60	70	50	60	80	20	100	2	3	Pasture, hay, corn.
Unprotected	70	30	50	60	80	50	------	30	50	30	40	60	------	90	5	5	
Chagrin silt loam:																	
Protected	100	70	70	90	100	90	------	50	70	60	60	80	20	90	2	3	Do.
Unprotected	70	30	50	60	80	50	------	30	50	30	40	60	------	80	5	5	
Palmyra gravelly loam	60(80)	50(80)	60(90)	70	70(90)	70(100)	------	70	60(100)	60(70)	30	60(80)	60(80)	60	4	2	General, alfalfa, beans.
Darien loam	50(70)	50(80)	50(80)	70(90)	60(80)	60(80)	------	40(60)	50(70)	50(60)	30	60	40(60)	70	5	3	General.
Howard gravelly loam	50(80)	50(80)	50(80)	60	50(80)	60(80)	------	50(70)	60(90)	60(70)	20	50(80)	50(80)	50	5	3	General, alfalfa, beans.
Wooster gravelly loam, alkali-subsoil phase	50(70)	40(60)	50(80)	60(80)	50(70)	50(60)	------	40(60)	50(80)	60(80)	20	60(80)	50(80)	60	5	3	General, potatoes, beans.
Wooster gravelly loam	50(70)	40(60)	50(80)	50(80)	50(70)	40(60)	------	30(50)	50(80)	70(90)	20	60(80)	50(80)	60	5	3	Do.
Wooster gravelly loam, compact-subsoil phase	50(70)	40(60)	50(80)	50(80)	50(70)	40(60)	------	30(50)	50(80)	60(80)	20	60(80)	50(80)	60	5	3	Do.
Chenango gravelly loam	50(70)	50(70)	50(70)	60	50(70)	40(70)	------	40(50)	60(90)	50(90)	20	50(80)	40(70)	40	6	3	Do.
Darien silt loam	40(60)	40(60)	50(70)	50(70)	50(70)	40(60)	50(60)	20(40)	30(40)	40(50)	30	50	30(40)	60	6	5	Hay, corn, oats.
Howard gravelly loam, rolling phase	50(70)	40(60)	40(70)	50	40(60)	40(70)	------	50(70)	50(70)	60(70)	20	40(70)	50(80)	40	6	4	General.
Mentor fine sandy loam	50(70)	40(60)	50(70)	60	40(60)	40(60)	------	40(60)	50(80)	50(90)	20	50(80)	40(70)	40	6	4	Potatoes, alfalfa.
Bath gravelly loam	40(60)	40(60)	50(70)	60(70)	50(60)	40(60)	------	20(40)	30(50)	50(70)	20	40	40	50	6	5	General.

Caneadea silt loam:															
Drained	50(70)	40(60)	50(70)	70	70(80)	50(60)	70	20(30)	30(40)	30(40)	20 30	[8]40	70	6	5	Hay, corn, oats.
Undrained	40	30	30	60	50	40	60	10	20	20	20 30	20	60	7	7	
Lansing silt loam, imperfectly drained phase.	30(60)	40(60)	50(70)	70	50(70)	40(60)	------	20	30	40(50)	40 60	[8]40	70	6	5	Hay, pasture.

[1] The productivity of each of the various soil types for each specific crop is compared to a standard (100), which stands for the inherent productivity of the most productive soil (or soils) of significant acreage in the United States for that crop. Figures indicate the inherent productivity of the soils for the specified crops, whereas figures in parentheses indicate the productivity under current practices which include the use of soil amendments, such as lime and commercial fertilizers.

[2] With such items as tame-grass hay, vegetables, and tree fruits, each of which includes a group of associated crops, the rating indicates the productivity of the soil type for that member of the group best adapted to the soil in question. In Wyoming County, timothy and apples were used as criteria for the tame-grass hay and tree fruits, respectively. (See footnote 8 concerning pears.)

[3] Vegetables doing best on organic soils, e. g., onions, celery, lettuce.

[4] Vegetables not requiring highly organic soils.

[5] The inherent-productivity grade refers to the relative ability of the soil to produce without amendments. Refer to the text for further explanation. When 2 inherent-productivity ratings are given, the upper number refers to the rating when the land is drained and/or protected from flood, and the lower to the rating when the land is undrained and/or not protected from flood.

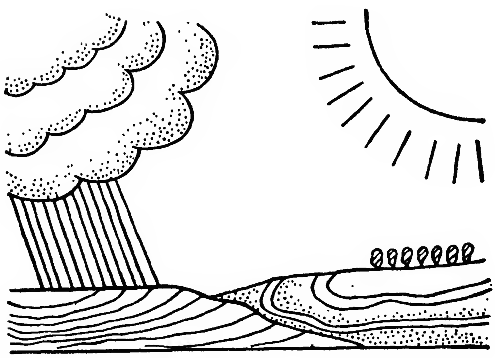
[6] This classification indicates the comparative general productivity of the various soils in the county, under the current farm practices with amendments. It is determined in the same general way as the inherent-productivity grade.

[7] Indexes refer to smoother areas (strongly rolling areas would have a lower rating).

[8] These indexes refer to pears as the best adapted tree fruit to the soil.

NOTE.—Leaders, according to position, indicate either that the crop is not commonly grown because of poor adaptation, or that amendments are not commonly used.

Soils of the United States



A MAP of the soil associations of the United States is included at the end of this Yearbook. It represents an attempt to bring together and summarize, on a comparatively small scale, the data accumulated during the past half century on the enormous variety of soils in this country. Local details have necessarily been submerged in order to present a general view of the features of broad significance. Much of the information about Puerto Rico and Hawaii is new and has never been published before.

The following pages (Part V of the Yearbook) describe these associations and the soils that compose them. The descriptions are to be used in conjunction with the map. The associations are arranged under the great soil groups. First there is a description of the region dominated by the great soil group, and then more detailed descriptions of each soil association within the region. These descriptions include the geographic setting, the climate, the native vegetation, the parent material from which the soils have developed, the characteristics of the soils themselves, and their general uses.

Each association, as it is shown on the map, represents a particular type of landscape, defined according to the character of the soils that compose it and the pattern of their distribution. Thus the map and the descriptions constitute a compact "soil atlas" of the entire United States and its Territories and possessions, as complete as it can be made within the space available.

In the index at the end of this volume, all of the soil associations given on the map are listed alphabetically under the general heading, Soils of the United States, with references to the page numbers on which the descriptions appear in this part of the Yearbook. To look up any particular soil association, it should first be found in the index.

Soils of the United States

By The Soil Survey Division,[1] Bureau of Chemistry and Soils

THE land occupied by the several States and Territories of the United States has an enormous range in all of its physical characteristics. The soil of any place is the synthetic product of all the forces in the landscape, and since there are a great number of combinations of biological, geological, and climatic conditions in this country, there are a great many types of soil. Some differ from one another in only one or two particulars; others differ fundamentally in every respect and have no common characteristics. Relatively broad areas may have similar soils; elsewhere there may be an intimate pattern of strongly contrasting types.

Temperatures vary from those of the tundra region of northern Alaska and the everlasting ice and snow of the high mountains, to those of the canefields of tropical Puerto Rico. The annual rainfall varies from a few uncertain inches in the southwestern deserts to more than 40 feet in some parts of Kauai Island in Hawaii. The native vegetation differs correspondingly. There are dense evergreen forests, mountain meadows, mangrove jungles, prairies of all kinds, scanty desert shrub land, tropical rain forests, and many other types. Vegetation has found a foothold in nearly every kind of earth formation.

All sorts of rocks have weathered in place—granites, sandstones, limestones, shales, and many others—to form soil material. Continental and mountain glaciers have left large deposits, streams have built great alluvial deltas and terraces, volcanoes have spilled lava over large areas, and the wind has piled drifts and dunes. Some of these soil materials are young—only a few years, or even days, old—others have been in place for many centuries.

Such is the complexity of the natural environment responsible for the formation of our soils. How soils are developed under these different conditions has been described in the article on soil formation (p. 948). In the discussion of soil classification (p. 979) the basic principles for defining and classifying soils were explained. The researches of the Soil Survey Division have already established several thousand soil types. The detailed pattern of these can be shown only on large-scale maps, 1 inch to the mile, or even larger in some instances. In compiling generalized soil maps from highly detailed, large-scale maps, it is not possible to combine areas of specific soil types into larger areas, corresponding to simple taxonomic groups. Two or more contrasting soils, each belonging to a distinct taxonomic group, may exist side by side in such an intimate pattern that individual areas can be shown only on a very large scale map. Idealized schematic maps showing only the major types of soil formation are based, almost wholly,

[1] This discussion and the accompanying map, Soil Associations of the United States (at the end of the Yearbook), have been prepared by the staff of the Soil Survey Division through the selection, interpretation, and summarization of data gathered over the past 40 years. Thus the work of hundreds of scientists in the Department and in the cooperating State institutions has contributed to this article, directly and indirectly. Special credit is due to J. K. Ableiter, Mark Baldwin, W. T. Carter, A. P. Dachnowski-Stokes, F. A. Hayes, W. E. Hearn, C. E. Kellogg, M. H. Lapham, T. D. Rice, R. C. Roberts, James Thorp, and F. O. Youngs of the Division, and to W. J. Latimer and A. T. Strahorn, formerly with the Division and now with the Soil Conservation Service. R. F. Turnure, Soil Survey Division, is chiefly responsible for the cartographic work.

on the normal upland soils of the region without regard to associated soils, although these may be of great importance agriculturally. That is, even though two areas are Chernozem, one may be far superior to the other for the production of wheat because of smoother relief or freedom from stones.

The map of soil associations of the United States appearing at the end of this volume has been compiled by the assembling and interpretation of existing soil maps and other soil researches. Each area as shown on the map consists of several or many soil types associated together in an individual pattern. The purpose of the map is to show those areas of soil associations significant to the development of agricultural communities and at the same time keep the scale small enough to permit their relationships to one another to be seen readily. By employing a larger scale, subdivisions in these areas might be added, but with such an increase in complexity as to make broad relationships more obscure. It is not possible to determine the exact soil conditions on individual farms from any map of such small scale, and for this purpose detailed soil maps must be consulted.

In this map, soils have been grouped in geographic associations. Such a grouping does not or cannot parallel the grouping of soils in a taxonomic system of classification. In a logical system of classification the soil types are placed into groups of progressively higher and higher categories according to their individual characteristics, quite regardless of the complexity of their distribution. Because an oak tree and a pine tree are growing side by side is no reason for placing them in the same taxonomic group of plants. Similarly, because the soil series, Miami, Crosby, and Brookston, are found side by side is no reason at all for placing them in the same taxonomic group. As a matter of fact, because of fundamental differences in their characteristics, each belongs in a different great soil group. Yet a map of vegetation can be made by showing the distribution of defined plant associations. In the same way geographic associations of soils must be defined for generalized maps.

Each area shown on this map is characterized by a particular pattern of soil series, types, and phases, defined according to their internal characteristics—the color, structure, texture, consistence, and other properties of the horizons, and their thickness and arrangement in the soil profile—and their external characteristics of relief (including slope and drainage), stoniness, climate, and native vegetation. The names of the associations are derived by combining the names of two or more important soil series in the association. Each area is described in the text according to the geographic pattern of soil types that comprise it and the internal and external characteristics of those types, especially in respect to those that influence the use and conservation of the soil.

In order to bring out the broader relationships even more clearly, the individual areas have been grouped according to the great soil group in which the dominant soils of the association belong. Thus, in the group of Podzol soils the dominant soils in each of the associations belong with the taxonomic group called Podzol, but not all of them are Podzol soils. In this instance, the Podzol refers to a broad association of soils including the true Podzols and their intrazonal and azonal associates, many of which are entirely unlike the true Podzol.

PODZOL SOILS

Podzol soils are developed in cool-temperate—occasionally in temperate—humid climates under the influence of coniferous, deciduous, or mixed forest vegetation. Highly siliceous materials are most susceptible to podzolization. Podzol soils are characterized (fig. 1), in undisturbed forest areas, by a surface mat of partly decayed leaves and wood fragments, over a very light gray leached layer averaging a few inches thick, with or without a very thin dark-gray mineral-humus horizon between. The upper subsoil (B_1 horizon or orterde) is brown or dark brown, somewhat heavier textured than the surface soil, and grades through the yellowish-brown, moderately heavy, lower B horizon to the parent material. The solum is usually less than 3 feet thick. Most of the Podzols are strongly acid and have a low natural productivity for cultivated crops, but those having a texture as heavy as sandy loam or heavier may be limed, fertilized, and used for general farming and for grass and other crops in support of dairying. Where these soils are used for potatoes, the amount of lime added should not be sufficient to raise the soil reaction to neutral and so encourage scab development. Much of the land within the Podzol area is either too stony or too sandy for profitable agri-

culture and is therefore used for forests. In transition zones, the Podzols are in close association with Brown Podzolic, Gray-Brown Podzolic, Prairie, and Chernozem soils.

Berkshire-Worthington Areas

Geographic setting.—Berkshire, Worthington, and associated soils occupy long, rather narrow belts in Vermont, New Hampshire, and western Massachusetts. The country is an undulating to rolling or ridgy plateau. Drainage is well established except in some of the depressed areas and lower slopes. Elevations range from 1,200 to 1,800 feet. Much of the land is forested.

Climate.—Cool and moist. Precipitation 35 to 45 inches. Summers, short and cool. Winters, long and cold. Frost-free season 120 to 130 days.

Native vegetation.—White pine, beech, white and yellow birch, hard maple, and hemlock.

Parent materials.—Glacial till derived from schist (Berkshire, Lyman, Blandford

FIGURE 1.—Podzol profile developed in dune sand in northern Michigan. Note layer of dark leafmold at the surface (A_0 and A_1), extremely irregular, ashy-white, leached horizon (A_2), and dark-colored orterde (B_1).

soils), from schist interbedded with dark impure limestone (Worthington, Greensboro, Calais, Peru soils), or similar materials in kames (Danby soils).

Soils.—Berkshire soils in timbered areas have a surface layer of duff underlain in turn by an ashy-gray layer and a rusty-brown, slightly firmer layer (thicker than in Hermon soils). This grades into a pale yellowish-brown and then into a greenish-gray, rather compact, platy-structured, gritty till at about 24 inches. Bedrock lies from 5 to 20 feet below the surface. About three-quarters of the area is stony. Lyman soils are shallower and stonier (less than 3 feet to bedrock).

Blandford soils are browner, less developed, and contain little stone; Worthington soils have profiles similar to the Blandford; Greensboro soils, developed on the hillsides, have profiles similar to the Berkshire; Calais soils on smooth ridge tops have shallow, weakly developed solum; Peru soils are developed in poorly drained depressions and slopes; Colton soils (described under Hermon-Colton areas) are

on outwash plains and terraces; and Danby soils are similar loose, open soils, but are upon the hummocky, broken surfaces of kames.

Use.—Stony areas are largely in forest and pasture, and more stone-free areas are cultivated. The principal crops are timothy, clover, oats, and potatoes, which produce fairly good yields. Worthington, Greensboro, Calais, and Peru soils are excellent for grass. Danby soils have low agricultural value.

Care should be exercised to control erosion, which is active on land in clean-cultivated crops. Use of manure or commercial fertilizers is essential to maintenance of a satisfactory level of productivity, and lime is beneficial to most crops.

Caribou Area

Geographic setting.—Caribou and associated soils occupy a ridgy plateau in the northeastern corner of Maine. The undulating ridge tops lie about 500 feet above sea level, have long gentle slopes, and are separated by narrow valleys. There are many small, poorly drained depressions scattered throughout the uplands.

Climate.—Cool and moist. Annual precipitation 30 to 35 inches. Winters, long and cold. Summers, short and cool. Frost-free season 95 to 105 days.

Native vegetation.—Yellow and white birch, beech, hard maple, fir, red spruce, and white pine on the better drained areas, and arborvitae, black spruce, and tamarack in poorly drained places.

Parent materials.—Glacial till derived from calcareous shales and limestone.

Soils.—Caribou soils cover about half the area. Under forest, Caribou loam has a layer of duff 2 to 4 inches thick underlain in turn by a gray floury loam 1 to 2 inches thick, and a dark-brown or rusty-brown firmer layer 3 to 6 inches thick, grading into a yellow-brown, firm but friable loam and at 15 inches into a pale-yellow material of the same texture and structure. At about 24 inches lies the substratum of firm, greenish-gray, little-modified till, underlain by bedrock at 3 to 6 feet below the surface. The soil is acid but the underlying parent material is alkaline. Drainage is good.

Easton soils occupy imperfectly or poorly drained positions and have gray, silty surface soils over mottled subsoils. Washburn soils occur in similar situations. They have dark surface soils over mottled subsoils. Van Buren and Keegan soils occupy the terraces. Van Buren soils have brown mellow surface soils and yellow-brown friable subsoils over gravel at 2 feet. Drainage is good. Keegan soils are poorly drained. They have dark-gray floury surface soils about 10 inches deep and mottled gray and brown silty subsoils resting at 20 inches upon sands and silts mottled with gray and rusty brown. Aroostook soils lie on bottom lands. They are mellow, silty, and well-drained.

Use.—Caribou soils are extensively used for potatoes, which yield heavily. Large amounts of fertilizer are used. Erosion is rather serious on potato land. Timothy, clover, oats, and buckwheat are also grown. Easton soils are used for oats, buckwheat, and hay. Washburn soils are largely forested, with cleared areas in hay and pasture. Van Buren soils are successfully farmed. Keegan soils are used for hay, oats, and pasture; and the Aroostook soils for hay and pasture.

Dekalb-Leetonia Areas

Geographic setting.—Dekalb and Leetonia are the dominant soils of the higher Appalachian plateaus and the more rugged Appalachian ridges in Virginia, West Virginia, Pennsylvania, and extreme southern New York. One large area is coextensive with the high plateau region through eastern West Virginia and central and northern Pennsylvania. Smaller areas appear as nearby and associated higher ridges of the general Appalachian region. Elevations range from about 1,500 feet to 3,000 feet or more above sea level.

Climate.—Average annual rainfall ranges from 35 to 40 inches, well distributed throughout the year. Relative humidity is moderately high, rate of evaporation low; considerable foggy and cloudy weather; average frost-free period 130 to 150 days.

Native vegetation.—Mixed conifer and hardwood forest, in which white pine, hemlock, sugar maple, red maple, oak, and birch are prominent trees.

Parent materials.—Weathered sandstones, shales and conglomerates; noncalcareous and highly quartzose.

Soils.—Dekalb soils are dominant. They are shallow, generally stony, and

occur on sloping and steep lands. They are marked by (1) a definite layer of matted brown organic matter on the surface; (2) gray to yellow, mellow, generally siliceous surface soil, which ranges from 6 to 12 inches thick; (3) a slightly heavier subsoil, yellow or yellowish brown in color, absent on the steeper slopes; and (4) disintegrated bedrock. A large proportion of the land is stony. Leetonia soils occupy smoother, plateau areas, and while developed from the same materials as the Dekalb soils, are deeper and exhibit the typical Podzol profile with the characteristic ashy, light-gray leached layer underlain by a coffee-brown mellow layer over the disintegrated parent rock. The Clymer soils are associated with the Dekalb and Leetonia in places, but are derived from shales, and consequently have clayey subsoils and substrata. Lickdale soils occupy small wet areas.

Use.—Most of the land is too steep and stony for cultivation (fig. 2). Such land is in forest of variable stand and quality. The better stands of saw timber have been cut out, but there is still local and wood-lot cutting for lumber, posts, and firewood. The better and more level areas are cleared and in pasture, hay meadow, or cropland. Farming is of the dairy or general farm type, with hay a prominent

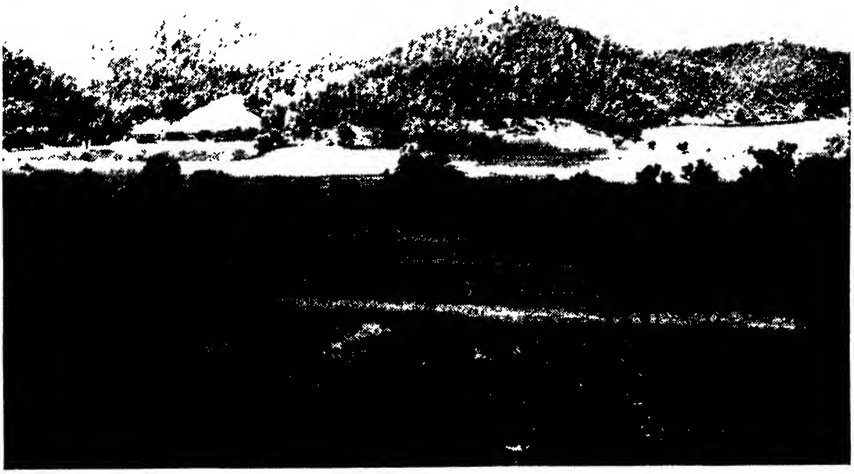


FIGURE 2.—Typical landscape in Greenbrier County, W. Va., showing Dekalb soils on the forested hills; the narrow valley in the foregound is occupied by Pope silt loam, a productive alluvial soil.

crop. Corn, oats, potatoes, and buckwheat are raised, the corn mostly for silage. Yields are generally low.

Complete commercial fertilizers are needed to supplement manure if higher yields are desired. Lime and phosphorus improve the growth of grasses.

Hermon-Colton Areas

Geographic setting.—Hermon, Colton, and associated soils are situated largely in Maine, New Hampshire, and northern New York, with narrow belts in the mountains of eastern New York, northern New Jersey, and eastern Pennsylvania. The land is smooth or undulating to rolling or strongly rolling and largely forested, with comparatively small areas of cleared farming land. Drainage is good.

Climate.—Average annual precipitation ranges from 40 to 50 inches. Summers, rather short and cool; winters, long and cold, with much snow. Frost-free season ranges from 100 to 120 days.

Native vegetation.—Red spruce, balsam, white pine, white and yellow birch, aspen, and hard maple.

Parent materials.—Largely glacial till derived from granite and gneiss, and outwash from this till.

Soils.—Hermon stony sandy loam is one of the more extensive soils. On the surface in virgin areas of this soil is a layer of forest duff 3 to 5 inches thick, underlain by a dark-brown layer of mull about one-fourth inch thick. This rests on a 3- to 4-inch layer of gray sand of single-grain structure under which is a rusty brown, fluffy sandy loam containing indurated lumps in places. This layer averages about 5 inches in thickness and grades into a yellow-brown, firm, friable sandy loam, and at an average depth of 20 inches into grayish-yellow, gritty till, and below 24 inches into unmodified gray till. The soil and subsoil are acid throughout. Boulders are scattered over the surface and imbedded in the till.

Canaan soils are developed on areas of shallow till over bedrock within 3 feet of the surface. Becket soils, developed on compact till, mostly from gneiss, have a thick brown layer below the duff and have a substratum of compact, platy, greenish-gray material at about 24 inches. Colton soils occupy rather flat terraces and outwash plains associated with the Hermon and Berkshire soils. They have substrata composed largely of granitic sand and gravel lying at an average depth of about 20 inches, and internal drainage is good or excessive.

Use.—Hermon and Canaan soils are largely in forest. Short growing season and stoniness of the land limit choice of crops and use of land. Cleared areas are used for pasture, hay, oats, rye, potatoes, and garden vegetables. Yields are rather low. Much land has been abandoned. A larger proportion of Becket and Colton soils is farmed and yields are slightly higher.

Iron River-Milaca Areas

Geographic setting.—Iron River, Milaca, and associated soils occupy much of the forested upland around the head of Lake Superior. Surface features range from nearly level plains to morainic ridges and bare rocky knobs. Many glacial lakes and bogs dot the landscape. There are extensive tracts of cut-over lands, communities of small farms, and many recreational, fishing, and hunting resorts. Elevations range from somewhat less than 1,000 feet to more than 2,000 feet above sea level, the highest point being in the Porcupine Mountains of Michigan.

Climate.—Continental, marked by wide annual variation in temperature. Winters are long and cold with extreme minimum temperatures of $-40°$ to $-50°$ F.; summers are relatively short and cool; and the average frost-free season ranges from about 125 to 90 days or less, depending on altitude and latitude. Proximity to Lake Superior moderates temperatures in narrow bordering areas. Precipitation ranges from about 26 inches in the southwest to 34 inches in the northeast, with about two-thirds coming in the growing season. Snow commonly covers much of the area from November to April.

Native vegetation.—Coniferous and hardwood forests, varying with soils and location, originally occupied the land—white pine, hemlock, yellow birch, and maple common on the heavier soils, and red (Norway) and jack pine on the sandier sites. There were very few, if any, hemlocks in Minnesota. Most of the merchantable timber has been cut, and many sections have grown up into a brushy cover of aspen, white birch, and pin cherry.

Parent materials.—Glacial drift of Wisconsin age, varying in composition with source of material—from underlying granites and gneisses in the eastern part, sandstone and basic igneous rocks farther west, transported lacustrine clays in places, and, in Minnesota, calcareous materials transported from limestone farther northwest.

Soils.—The soils are mostly Podzols but have many variations in profile and in external features—relief, drainage, and vegetation. Iron River and Milaca soils have similar and characteristic Podzol profiles, characterized by: (1) 1- to 3-inch layer (A_0) of forest litter and trockentorf (forest mat); (2) very thin surface layer (A_1) of dark humus; (3) gray leached subsurface layer (A_2) of medium texture about 4 inches thick; (4) dark-brown silt loam or loam subsoil layers (B_1 and B_2), 15 to 30 inches thick—in places slightly cemented—and coarser in texture in the lower part; and (5) parent glacial material of unassorted material.

The Iron River silt loam and Milaca very fine sandy loam probably are the dominant members of their series. The chief distinctions between the two series are the yellower color, higher clay content and greater compaction of the B horizon

of the Iron River soils and their higher content of dark-colored basic rock materials, and the very slight cementation of the coarser material in the B horizon of the Milaca.

Among the soils associated with the Iron River in Michigan are the Hiawatha, Baraga, Stambaugh, and Vilas soils, differing principally in drainage, degree of cementation of B horizon, character of parent material, and relief. Among the associates of the Milaca soils are the Onamia, Greenbush, and Freer. The Kennan soils, mapped and described by the Soils Department, University of Wisconsin, are not essentially different from the Iron River and Milaca. Few detailed soil surveys have been made in this area and much remains to be learned about the soils.

Use.—These areas are representative of the cut-over lands of the Lake States. Much of the land remains in brush and timber. Mining is very important in the Iron Range. Recreational facilities are available throughout the area. Agriculture is most widely developed in the south. Dairying and subsistence farming prevail. The principal crops are timothy and clover hay, oats, and potatoes. The shortness of the growing season is unfavorable for corn. Stoniness handicaps profitable use of much of the land for crops. Distribution of soils suitable for farming is closely related to the distribution of swamps, moraines, and outwash plains. Settlement is largely in local communities on the better soils. Narrow areas bordering Lake Superior have a climate favorable for and are devoted to production of tree fruits, especially cherries.

Lackawanna-Culvers Areas

Geographic setting.—The Lackawanna-Culvers areas embrace glaciated parts of the scenic Appalachian Plateau in southeastern New York, northeastern Pennsylvania, and a small part of northern New Jersey. The plateau was dissected into long, narrow ridges and deeply incised valleys before the advance of the glacier. Glacial ice followed the valleys, covered the ridges, and broke up and redeposited the underlying sandstone and shale rocks. Valley floors lie 1,000 to 1,200 feet and the ridges 2,000 to 3,500 feet above sea level. Smoother areas in valleys and on ridge tops are cleared and large areas remain in forest. Large farm homes owe their prosperous appearance to patronage by summer vacationists rather than to the productivity of the land.

Climate.—Cool-temperate and humid—precipitation 35 to 50 inches. Long cold winters; short cool summers.

Native vegetation.—Oak, maple, beech, birch, hemlock, and formerly chestnut. Laurel, rhododendron, and huckleberry underbrush.

Parent materials.—Glacial drift, largely composed of Indian-red and purplish sandstones and shales with some gray sandstone and minor amounts of other rocks.

Soils.—Lackawanna soils are weakly developed Podzols with organic mat, thin pinkish-gray loamy surface soils, reddish or pinkish-brown gravelly loamy or silty subsoils, compact reddish or purplish glacial till, and with Indian-red or purplish sandstone and shale bedrock 30 to 48 inches from the surface. Culvers soils are developed from materials similar to those of the Lackawanna soils but are imperfectly drained, and are mottled with gray and rust in lower horizons. They occur on seepy slopes. Well-drained Walton soils and imperfectly drained Wellsboro soils are developed on deep, compact, rolling valley till. Tunkhannock soils on river terraces and Colchester soils on kames have well-developed podzolic profiles and are good agricultural soils. Barbour soils are developed on well-drained pinkish recent alluvium.

Use.—Silage corn, hay and pasture grasses, contributory to the dairy industry, are principal crops. Yields are fair when soils receive lime, manure, and complete fertilizers. Much of the land remains in woods.

Erosion is not a serious problem because little steep land is under clean cultivation.

Lakewood-Dukes Areas

Geographic setting.—The Lakewood-Dukes area includes very sandy parts of the Coastal Plain from southern Delaware to the tip of Cape Cod, and is especially important in southeastern New Jersey and southern Long Island. It comprises an undulating to nearly flat sandy plain, covered with scrubby original or second-growth oak and pine forest, and nowhere exceeds 500 feet above sea level. It is

contiguous to and overlaps the Sassafras-Collington area in Delaware and New Jersey and the Gloucester-Plymouth area on Long Island and Cape Cod.

Climate.—Forty to forty-five inches precipitation—about 21 inches falling from April to September, inclusive. Frost-free season of 170 to 190 days. Winter and summer temperatures moderated by oceanic influence.

Native vegetation.—Scrubby oak and pine, huckleberries, ferns—cedars in swamp. Reeds, sedges, and grasses in marshes.

Parent materials.—Quartz sands and gravels in New Jersey and Delaware—quartz and arkose sands and gravels on Long Island and Cape Cod. Silts, clays, and peat in tidal marshes.

Soils.—Virgin Lakewood and Dukes soils both have a surface organic mat, a whitish-gray sand surface soil, a coffee-brown upper subsoil high in acid organic matter, 1 to 3 inches thick, and a yellow-brown loamy sand or sand deeper subsoil. Parent materials are largely of sand, with some gravel in the Dukes. The soils are very strongly acid in reaction. The chief difference between the Dukes and the Lakewood is that the grayish-white surface soil averages 8 or 10 inches thick in the Dukes and 20 or 30 inches thick in the Lakewood. Included Plymouth sand and sandy loam soils contain some glacial boulders and some grains of feldspar. Gray-brown Sassafras sands are included as fairly large areas, especially in New Jersey, and Sassafras loam and silt loam, very productive soils, are included as small areas. Peat and dark-colored sandy soils, such as Portsmouth and St. Johns sands, occur in depressions, and there are large areas of peaty tidal marsh along estuaries. Many other minor types are included.

Use.—Lakewood, Dukes, Plymouth, and Sassafras sands are suitable only for forestry, recreation, and chicken farms. They are among the poorest soils in the United States for agricultural purposes. Included small areas of heavier types of Sassafras soils have a high value for general agriculture and vegetable crops. Wild blueberries are harvested in much of the area and cranberries are cultivated to a limited extent on the soils of boggy areas.

Ontonagon-Trenary Areas

Geographic setting.—This group of soils occupies a number of relatively small areas in northern Michigan, northern Wisconsin, and northeastern Minnesota. They are definitely within the region of Podzol soils but are only in part Podzols, since the highly calcareous parent materials have inhibited the development of the Podzol profile to a great extent. These areas are associated largely with the Iron River-Milaca and Roselawn-Rubicon areas within the region of Wisconsin glacial drift. The Ontonagon and associated soils occupy old lake plains which are generally level. These lake plains border, for the most part, the present Great Lakes. The Trenary and associated soils occur on more irregular and rolling glacial plains. The elevation ranges from about 600 feet above sea level adjoining Lake Huron to about 1,000 feet in southern Ontonagon County, Mich.

Climate.—Humid with relatively low rate of evaporation. Temperature is moderated by the Great Lakes. Average annual precipitation ranges from about 28 inches to more than 30 inches, 50 to 75 percent of which falls during the period from April 1 to September 30. The frost-free period ranges from 140 days or more near the Great Lakes to 110 days in the interior.

Native vegetation.—Mixed hardwood and coniferous forest with the hardwoods dominant over most of the area. The dominant conifers are white pine and hemlock. Hardwoods are mostly sugar maple, beech, yellow birch, and white birch. Tamarack and black spruce are prominent species in the timbered bogs.

Parent materials.—The parent materials consist chiefly of glacial drift of the Wisconsin age, pinkish or reddish in color, and, for the most part, highly calcareous. Limestone bedrock is near the surface in those areas in northern Michigan bordering Lake Michigan and Lake Huron. Areas that border Lake Superior are dominantly of water-laid, fine-textured materials derived from the reddish glacial till of the region.

Soils.—The Ontonagon soils, chiefly in Ontonagon and Chippewa Counties, Mich., represent the group of soils developed from lake-laid sediments. They are Podzol soils with a definite organic mat, underlain by a light gray, loose, silty or fine sandy layer which ranges from 6 to 12 inches thick and constitutes the main part of the surface soil. The subsoil is pale red or, on more level areas, slightly mottled silty clay which extends to a depth of some 16 or 18 inches. The substratum is red or pinkish clay, highly calcareous and laminated. The Trenary

soils are Podzol soils developed from rather sandy calcareous till which occupies gently rolling or undulating areas. They are definitely siliceous throughout and the depth to lime ranges from 3 to 4 feet. The Onaway soils, which are important in parts of the northern section of the lower peninsula of Michigan and in northeastern Wisconsin and adjacent Michigan, are developed from very highly calcareous, loose, gravelly glacial till. They are not definitely Podzols, except where the soil materials are exceptionally sandy. Associated with all of these soils are Half Bog soils which are, for the most part, dark-colored and rich in organic matter. They are naturally poorly drained but where cleared support excellent pasture. The wetter lands are, for the most part, occupied by peat deposits, in places weathered to form black muck.

Use.—These soils are in general very fertile (fig. 3). Where not too stony or shallow, large areas have been cleared and are under cultivation to alfalfa, clover, small grains, and corn for silage. The stonier, rougher, and wetter lands produce pasturage and hay. Dairying is the chief type of farming. Limiting factors in agricultural production over some of the area are shallow, stony, or wet soils, the

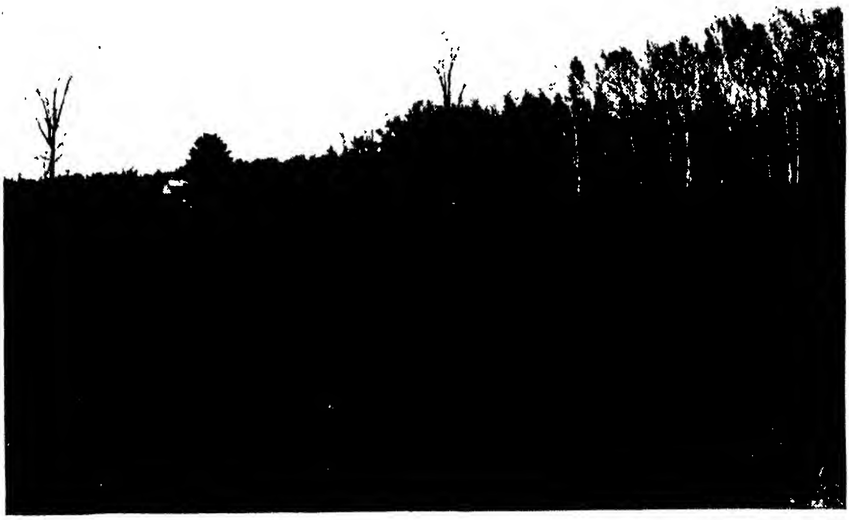


FIGURE 3.—Typical landscape of the Ontonagon soils in Chippewa County, Mich. The cleared areas are well adapted to hay and pasture, but much of the land is still in timber and brush.

cost of clearing, relative inaccessibility, and difficulty of building and maintaining roads.

Roselawn-Rubicon Areas

Geographic setting.—The Roselawn-Rubicon association of soils includes very sandy Podzol soils in the northern Lake States region. The largest area forms most of the north half of the Southern Peninsula of Michigan. Smaller areas are scattered from the eastern part of the Upper Peninsula of Michigan westward to central Minnesota. All the areas form part of the northern glaciated region of the Middle West and exhibit the various topographic features of glacial drift—moraines, till plains, and outwash plains, hilly, undulating, or nearly level in relief. Elevations range from 580 to about 1,500 feet above sea level.

Climate.—Average annual precipitation ranges from about 25 inches in central Minnesota to 33 inches in parts of Michigan. In central Minnesota, 75 percent, in Michigan about 50 percent of the rainfall is during the warm season. Winters are long and severe with minimum temperatures falling to −50° F. in central

Minnesota. Summers are short and pleasant with temperature in places ranging up to about 100° on occasion. Both winter and summer temperatures are moderated by the Great Lakes and the growing season is longer near the Lakes. The frost-free period on the shores of Lake Michigan averages 150 to 160 days; in the area in central Minnesota it is 125 days.

Native vegetaiton.—Mostly pine, of which red and jack pine are the dominant species, but a considerable proportion of the area in Michigan is covered by hardwood, chiefly sugar maple, beech, and yellow birch. A few small prairies occur in the area in central Minnesota. Associated bogs are in part open and in part timbered with tamarack and black spruce.

Parent materials.—Glacial drift composed of sands or very sandy materials, mostly quartz; calcareous material absent or a very minor constituent.

Soils.—The Roselawn soils are well-drained Podzols of the rolling pinelands marked by (1) a surface layer of forest litter and a thin organic mat; (2) a very

FIGURE 4.—Cut-over and burned-over lands in the Roselawn-Rubicon soil area. The soils are sandy, infertile, acid, and droughty. These unfavorable soil conditions, combined with the high cost of clearing the land and poor transportation and market facilities, retard cultivation and settlement.

thin (¼-inch) dark gray layer of mixed sandy mineral soil and dark-colored fine organic matter; (3) a very light gray layer of quartz sand, 4 to 6 inches thick; (4) brown, more coherent sandy layer with the brown coloration fading downward through yellowish brown to pale yellow; and (5) parent material of grayish-yellow sandy gravelly unassorted glacial drift. The Rubicon sands are similar to Roselawn, but occur on nearly level plains, and are developed from assorted water-laid glacial drift, composed of sand. The Emmet and Kalkaska soils are analogous to Roselawn and Rubicon soils, but have been developed under dense hardwood forest, and the features of the Podzol are more strongly expressed in the soil profile. The top layer of organic matter is thicker and denser; the light-gray layer generally thicker; and the brown layer more intensely colored than in the Roselawn and Rubicon soils. Strongs and Blue Lake are similar associated soils. The associated Grayling sand occurs on plains like the Rubicon, but the drier more pervious material originally supported a thinner stand of jack pine, the Podzol profile is meagerly developed, and the soil is very droughty. The Menahga and Nymore soils of central Minnesota are similar to the Grayling but are somewhat loamier, with slightly more organic matter and more silicate minerals in the parent materials. The Vilas sands of Wisconsin are similar to the Roselawn soils. Associated wet soils throughout the Roselawn-Rubicon area are Newton, Saugatuck, muck, and peat.

Use.—Most of these lands are in timber or brush, practically all cut over (fig. 4),

and much of it burned over. Scant pasturage is furnished by such lands. Hay is taken from the Bog and Half Bog soils in places, and a few areas are cropped. A district in the northwestern part of the Lower Peninsula of Michigan is utilized for fruit, particularly cherries, and small scattered areas support a transitory agriculture, chiefly on the hardwood lands. Associated small areas of better soils are used, but in general the land fails to support a successful, profitable agriculture.

Climate, timber, streams, and lakes favor the use of the land for recreational purposes.

Taylor-Nebish Areas

Geographic setting.—A large area of Taylor, Nebish, and associated soils includes the undulating to rolling timbered plains of north-central Minnesota. The region is young, without a definitely developed drainage system. There are many lakes, ponds, and bogs. A few areas are sharply irregular or hilly. The extreme range in elevations is not great, and most of the area lies between 1,200 and 1,400 feet above sea level. A small area occupies the Turtle Mountains in central-northern North Dakota on the Canadian border.

Climate.—Winters are long and severe; summers short and generally cool. Average annual precipitation about 25 inches, nearly 75 percent of which falls between April 1 and September 30. Average annual snowfall 40 to 50 inches; frost-free season 100 to 110 days.

Native vegetation.—Originally densely timbered, except on some of the bogs, with conifers and hardwoods; prominent trees, white pine, balsam fir, white spruce, black spruce, yellow birch, hard maple, and oak, with jack pine and red pine on the sandier lands; aspen prominent in second growth.

Parent materials.—Glacial drift, of late Wisconsin age, chiefly gray calcareous heavy till. There are included areas of noncalcareous till, local sand deposits, and water-laid silts and clays.

Soils.—The dominant soils of the better drained lands of the area are of the Taylor, Beltrami, and Nebish series. The Taylor soils have (1) a thick matted layer of organic matter on the surface; (2) a striking light-gray leached layer; (3) a distinctly dark-colored subsoil, generally plastic clay or clay loam; and (4) at a depth of 1½ to 2 feet the gray, highly calcareous clay till which constitutes the parent material. The Beltrami soils are similar to the Taylor except in a distinctly higher content of lime in the parent material; the Nebish soils differ in being lighter textured or sandier throughout. Smaller areas of Rockwood soils, which are developed from gray noncalcareous till, occur chiefly in Hubbard County, Minn. Small scattered areas of very sandy soils are low in lime and plant nutrients and, unless in depressions or low flats, are droughty.

Use.—Land is largely in small and second-growth timber and brush. Only a small proportion is cleared and cultivated, owing to short growing season, severe winters, high labor cost of clearing, and relative inaccessibility of much of the area. Crops are chiefly hay, oats, and potatoes. Possibilities for use, aside from forest, are chiefly for dairying and a subsistence type of farming. Weeds are a serious problem, particularly on the heavier soils such as the Taylor.

BROWN PODZOLIC SOILS

Brown Podzolic soils are known only in the Northeastern States. The greater part occur in a belt of hills and valleys south of the Podzol area of New England, but the soils of the two groups are closely intermingled in their zone of transition. Essentially, the Brown Podzolic soil is an imperfectly developed Podzol having, in timbered areas, an organic mat on the surface and a very thin gray leached horizon just below it—usually less than an inch thick. The B horizon is largely yellowish brown in color and has only the beginnings of a dark-brown orterde just below the gray A horizon. The total depth of the solum is usually less than 30 inches although it exceeds that depth in places. The climate varies from temperate to cool-temperate and humid, but the effective moisture averages less than in the Podzols. Stony and very sandy areas remain largely in deciduous and mixed coniferous and deciduous forest. Many areas of the soils of sandy loam or heavier textures are cleared and used for pasture, hay, general farm crops, and fruit. Smooth, stone-free areas on stream terraces make excellent truck gardens and are intensively cultivated near the large cities of New England. The soils

are moderately to strongly acid and highly leached and therefore must be limed and fertilized heavily if they are to produce bountifully.

Gloucester-Plymouth Areas

Geographic setting.—Gloucester, Plymouth, and associated soils occur in New England, New York, and New Jersey upon smooth to gently rolling or strongly rolling country. Much of the land is very stony and is still forested, though there are many areas of farmed lands and pastures. Elevations range from sea level to 1,500 feet.

Climate.—Cool-temperate, and humid. Precipitation, 40 to 50 inches. Summers are short and moderate to cool; winters, rather long and cold. Frost-free season, 140 to 160 days.

Native vegetation.—White pine, hemlock, oak, maple, birch, alder, and tamarack.

Figure 5.—Characteristic stone wall on Gloucester loam. Many of these walls in parts of New England were built before 1866.

Parent materials.—Glacial till and outwash materials, mainly from granite and gneiss, in the form of ground moraines, terminal moraines, kames, terraces, and outwash plains.

Soils.—Gloucester soils are the dominant soils of the uplands in southern New England. They are commonly very stony (fig. 5), only about one-fourth of their area being classed as nonstony. Under forest the surface is covered with a layer of duff about 1 inch thick, grading into a thin layer of partly decomposed organic matter. This lies upon a 2-inch layer of dark-brown, fluffy soil—sandy loam to loam—grading imperceptibly into yellow-brown, firm but friable material of about the same texture, and at about 15 inches into a pale yellowish brown. At about 24 inches lies the gray, gritty, slightly compact unaltered till. Soil and subsoil have a single-grain structure and are acid throughout. Depth to bedrock is commonly between 5 and 10 feet.

Plymouth soils are somewhat similar to the Gloucester, but lie on rougher

land, have a looser, more open substratum, and are excessively drained. Essex soils lie on comparatively smooth areas, have a tight, compact till substratum, and are imperfectly drained. Whitman soils are developed in depressions, have dark-brown or black (mucky) surface soils over mottled gray and brown subsoils and gray water-soaked substrata. The Hinckley soils are developed on hummocky kames and are excessively drained.

Merrimac and Carver soils occupy terraces and outwash plains. Merrimac soils are mainly fine and medium sandy loams or loamy sands, containing more or less gravel. They have brown surface soils passing at about 5 inches into friable, yellow-brown material of similar texture, grading downward into pale yellow and at an average depth of about 20 inches into loose gray sand and gravel, mainly granitic. The substratum is porous and the soil is well-drained. The Carver soils of southern New England are older soils than the Merrimac, more highly leached in the surface soil and better oxidized in the subsoil. The parent material contains a large proportion of quartz. The Ondawa soils occupy well-drained bottom land. They are brown soils with yellow-brown to pale yellow subsoils, mellow throughout.

Use.—Stony areas of Gloucester soils are largely in forest. The area in tilled crops is small; there is a fair acreage of hay and more of pasture. Cleared areas used largely for dairying and to a small extent for growing vegetables and apples. Yields are fairly good. These soils do not seem to be deteriorating under present use.

The Plymouth soils are in woods or used for pasture. Essex soils are used for hay or pasture. Whitman soils are poorly drained and largely wooded with soft maple. Hinckley soils have low value for farming. Merrimac soils contain much of the cultivated acreage of the region, though some areas are timbered. Cleared areas are used for a variety of crops including market garden crops and tobacco. The organic content of the soil is low and commercial fertilizers are used to supplement manure in inducing productivity. Carver soils are largely in jack pine and scrub oak forest. Cleared areas are cultivated but are less productive than the Merrimac soils and hardly repay the cost of clearing. Ondawa soils are subject to overflow but are very productive and are used for hay, pasture, and corn.

Charlton-Paxton Areas

Geographic setting.—Charlton, Paxton, and associated soils occupy two long, narrow, northeast-southwest belts in central and southern New England. They lie on rolling or ridgy glaciated uplands. There are a large number of soil series in the area due to differences in parent materials. About one-half of the land is in forest and the remainder is used for cultivated crops and pasture. Elevations range from 100 to 1,200 feet above sea level.

Climate.—Cool-temperate and humid. Annual precipitation 40 to 45 inches. Summers are rather short and moderate or cool; winters, long and cold. Frost-free season 140 to 180 days.

Vegetation.—White and red oak, hard maple, gray birch, white pine, and, formerly, chestnut.

Parent materials.—Glacial till, largely from schist of variable composition, in places containing dark, impure limestone, slate, phyllite, and granite.

Soils.—Charlton soils contain less stone than the Gloucester. Stone consists largely of slabs. The surface soils to an average depth of 7 inches are brown, mellow, and of single-grain structure. Subsoils are rich yellow brown, firm but friable, and change at about 18 inches to pale yellowish brown, and at 30 inches to greenish-gray, gritty, somewhat compact till, which continues to bedrock at 20 or more feet below the surface. The entire profile is acid. Hollis soils are similar but have bedrock within 3 feet of the surface. Paxton soils are somewhat similar but for the most part have heavier, more compact subsoils and substrata; they are developed on drumlins.

Woodbridge soils occur on the side walls of the valleys where the till is very compact. Soil formation has proceeded to a depth of about 2 feet, below which is the raw compact till. Surface drainage is good, but subdrainage is poor.

Sutton soils, which occupy smooth or comparatively flat areas, are poorly drained and have darker and deeper surface soils and more pronounced mottling in the substrata than do other soils of this association.

Brookfield soils are developed from schist high in iron. They are highly acid and have rusty-brown mellow surface soils and upper subsoils over ocherous-

yellow, friable subsoils. Colrain and Shelburne soils are developed on till from mica schist interbedded with dark impure sandstone. Colrain soils are brown and fluffy with mellow, yellow-brown or brown subsoils and greenish-gray substrata over bedrock at shallow depth. Shelburne soils are similar but on deep, rather compact till.

Use.—About half the Charlton soils are used for farming, including dairying, orcharding, and market gardening. They are slightly more productive than the Gloucester and compare favorably with any of the upland soils of New England. Hollis soils are less productive and a larger area is in forest. Paxton soils are largely under cultivation. They are good soils for grass and are used for hay and pasture, though silage corn, oats, rye, buckwheat, clover, sweet corn, and potatoes are also grown. Yields are good. Woodbridge soils occupy steep lands and are largely in woods and pasture. Sutton soils are used largely for hay and pasture, but need underdrainage if other crops are to be grown. Hay, pasture, corn, and oats are important on the Brookfield soils. Colrain and Shelburne soils are excellent soils for grass and are also used for apple orchards.

Wethersfield-Cheshire Area

Geographic setting.—Cheshire, Wethersfield, and associated soils occur in the Connecticut Valley of Connecticut and Massachusetts on undulating to rolling glaciated uplands and smooth outwash plains. The uplands have an elevation of 300 to 400 feet above sea level and the plains about 200 feet. Much of the land is intensively cultivated and productive, though rougher or poorer areas are in forest.

Climate.—Cool-temperate and humid. Precipitation ranges from 30 to 58 inches in different years. Summers moderate. Winters, rather long and cold. Frost-free season averages 150 days.

Native vegetation.—Red and white oak, gray birch, walnut, hickory, and white pine. Scrub oak and pitch pine on Windsor soils.

Parent materials.—Glacial till and outwash from red sandstones, shales, and conglomerates.

Soils.—Cheshire soils, on undulating or rolling till areas, are pervious and well-drained loams and fine and medium sandy loams containing more or less gravel and stone. Under forest conditions there is a thin duff layer underlain in turn by a layer of about 3 inches of dark-brown mellow surface soil, with yellow-brown mellow material to about 10 inches, and pale reddish-brown, firm but friable material to about 24 inches, grading into reddish-brown, slightly compact sandy till. Wethersfield soils occupy drumlins. They have brown surface soils, redder and heavier subsoils, and compact substrata. Manchester soils, on kames of stratified sands and gravels, have color profiles similar to the Cheshire but are inclined to be excessively drained and droughty.

Hartford and Chicopee soils lie on the extensive smooth outwash plains of the Connecticut Valley. Both are friable and porous, and the Chicopee are excessively drained or droughty. Windsor soils, developed from wind-blown deposits, have a dunelike surface and are very droughty and subject to wind erosion.

Agawam soils, occupying terraces, are fine, mellow, brown or dark-brown soils over pale yellow-brown friable subsoils, changing to greenish yellow at about 20 inches and greenish gray at about 30 inches. At 40 inches lies the gray, sandy substratum. The Hadley soils occupy Connecticut River bottom lands that are occasionally flooded. They are greenish-yellow soils, slightly darker at the surface, and mellow throughout. The substratum, below 40 inches, consists of loamy sand. They are neutral to alkaline in reaction where commonly overflowed, and slightly acid in other places. Both Agawam and Hadley soils are highly productive.

Suffield soils are developed on greenish-gray silty to clayey bedded lake deposits, which are alkaline but not calcareous. Suffield soils have grayish-brown floury surface soils over yellow-brown to olive-yellow fairly heavy subsoils grading into the substrata at about 24 inches. Melrose soils are similar but have an overwash of sandy material.

Use.—Cheshire soils are used for timothy, clover, alfalfa, potatoes, tobacco, and apples. Yields are good under current farming methods, which include use of manure, lime, and commercial fertilizers. Wethersfield soils are used for the same crops except alfalfa. Manchester soils are for the same crops. Yields are good except in dry years. Hartford soils produce large yields of hay, potatoes, tobacco, and vegetables. They are liberally fertilized. Chicopee soils have little value for

farming. Agawam and Hadley soils are used for onions, potatoes, and tobacco, and produce exceptionally high yields with liberal fertilization. Hay, oats, and corn are also grown (fig. 6).

Suffield soils are fairly productive but are used mainly for hay and pasture. The sandier soils of the series are also used for tobacco and onions.

GRAY-BROWN PODZOLIC SOILS

Gray-brown Podzolic soils of the eastern and midwestern part of the United States are developed under deciduous forest and in a humid temperate climate. Geographically, they lie between the Podzols on the north and the Red and Yellow Podzolic soils on the south and join with the Prairie soils on the west. In the Pacific Northwest, areas of somewhat similar soils have been developed under coniferous forests. Typical members of the group have a thin leaf litter lying on

FIGURE 6.—Celery growing in Hadley very fine sandy loam. These soils are highly productive when properly managed and fertilized.

an inch or two of dark grayish-brown, granular, mild humus which in turn grades into a grayish-brown leached horizon which extends to a depth of 8 or 10 inches. The B horizon (upper subsoil) varies from yellowish brown to light reddish brown in color and is distinctly heavier in texture than the A horizon. In turn it fades in color with depth and the texture grades into that of the parent material, which may be medium, heavy, or light, according to the nature of the parent rock. Soil reaction is usually medium acid except for the slightly acid or neutral mild humus layer. In the Midwestern States where Gray-Brown Podzolic soils are developed largely on glacial till, they are intimately associated in an intricate pattern or network with members of the intrazonal order of soils, including Planosols, Wiesenböden, Bog and Half Bog soils. A similar association of soils characterizes the Eastern States, but the proportion of the normal soil is greater than on the till plains of Ohio and Indiana, and the pattern is more of a dendritic nature.

Productivity of the Gray-Brown Podzolic soils varies considerably according to

texture and to the nature of the parent material. In general, soils developed on more or less calcareous glacial till, on limestones, or on granites, gneisses, and schists are more productive than those developed on shales and quartz sands. Tremendous areas of these soils have been cleared and are used for general farming, corn, and small grains, and the sandy members near large cities, for truck and fruit crops. They are responsive to liming and to the application of organic and mineral fertilizers. In the Pacific Northwest the greater part of the land is either in forest or is cut-over or burned-over land. The cultivated area is comparatively small.

Clinton-Boone-Lindley Areas

Geographic setting.—These are areas of light-colored soils developed along the valley slopes of the Mississippi River and for a short distance along its tributaries at elevations ranging from about 550 to 1,250 feet above sea level. The most extensive areas are in Wisconsin, Minnesota, Illinois, Iowa, and Missouri. The slopes are largely covered by timber and the landscape presents a marked contrast to the surrounding stretches of smooth prairie. The surface varies from gently to sharply rolling, with no considerable areas of flat land. Clearings irregular in shape and size are interspersed among the hilly wooded areas.

Climate.—Typical of the Corn Belt. Average annual precipitation ranges from 30 to 37 inches, and the mean annual temperature from about 46° to 56° F.

Native vegetation.—Forests of mixed hardwoods, including white oak, red oak, hickory, elm, walnut, basswood, and hard maple.

Parent materials.—Mainly loess in thick beds, but locally in thin deposits over glacial drift or limestone and extensive deposits of glacial drift, sandstones, and, in comparatively small areas, shale and other soft bedrocks.

Soils.—Clinton silt loam, which is representative of the Clinton series, has a surface layer consisting of grayish-brown mellow silt loam. The upper subsoil is yellowish-brown or brown heavy silt loam. The lower subsoil is yellowish-brown silty clay loam, which breaks up into cubical clods that are often faintly coated with gray. Under this is the loose silty material from which the soil is derived. Fayette soils have surface soils similar to those of the Clinton soils but the subsoils are yellowish-brown silt loams and are friable throughout. Lindley soils have grayish-brown surface soils and moderately heavy subsoils overlying glacial drift. The soils of the Boone series are light-colored sandy soils developed over sandstone.

Use.—The greater part of this region is either uncleared and remains as woodland or is cleared and used for pasture. The cultivated acreage is comparatively small. The choice of crops and crop rotations depends largely on the slope. The smoother areas give good yields of corn, oats, and hay crops. Much of the hilly land is used for pasture in connection with livestock raising and dairying.

The slope of the land and the character of the soil material render the soil very susceptible to erosion where cultivated. Proper methods of cultivation, crop rotation, and the use of cover crops are essential to protect the land. As the soils are quite acid and lack organic matter, they show a ready response to lime and manure. Because of the types of farming and careful management, the farmers of many parts of these areas are more prosperous than farmers on the more fertile land of the black prairies.

Chester-Manor Areas

Geographic setting.—The Chester-Manor areas embrace disconnected parts of the northern Piedmont in Pennsylvania, New Jersey, Delaware, Maryland, and Virginia. Elevations are all less than 1,000 feet. The country is agreeably undulating to rolling, with a varied and beautiful landscape of well-tilled fields, rich pastures, and prosperous farm homes on the smoother parts, and luxuriant woodlands of tuliptree, various oaks and maples, and hickory on steeper stony areas. Chestnuts, formerly abundant, have been destroyed by oriental chestnut blight. The Penn-Lansdale and Sassafras-Collington areas are closely associated with this area throughout its length, and there is more or less overlap between the areas.

Climate.—Thirty-five to forty-five inches precipitation—somewhat more than half falling during the average frost-free season of 160 to 195 days. Summers moderate to hot and humid; winters moderately cold, but short.

Native vegetation.—Deciduous forests, varying in composition with soils and rocks. Cedar-scrub oak barrens on Conowingo soils.

Parent materials.—Strongly metamorphosed rocks—gneiss and schist with some serpentine; dark-colored igneous (trap) rocks, such as diabase and basalt; granite. Rocks mostly deeply weathered.

Soils.—Chester and Manor soils have grayish-brown loamy surface soils, yellowish-brown to light reddish-brown clay loam or clay deep subsoils with loose, nutlike structure, and loamy parent materials derived from the weathering of gneiss or granite and mica schist, respectively. There are important areas of moderately productive Montalto soils of loamy surface texture and reddish, clayey subsoils, derived from basalt; scattered areas of shallow and unproductive Conowingo soils of serpentine origin; scattered flat areas of unproductive Leonardtown soils in the southern part with hardpan subsoil and old coastal plain deposits as parent materials; and several others of little importance. Small areas of imperfectly drained soils around stream heads on the uplands and similar soils on narrow flood plains provide excellent pasture.

Use.—Land use, as a whole, is well adjusted to soil conditions. Dairying and general farming, including the production of corn, wheat, oats, hay, potatoes, and some vegetables and fruits, bring substantial incomes to the farmers, who find excellent markets in the large cities of the region. Chester soils are more productive than Manor. This is one of the richer agricultural areas of the United States.

Moderate sheet and slight gully erosion, especially on Manor soils, have forced the sodding of steeper areas, but the problem is not very serious. Phosphate and nitrogen fertilizers give excellent results.

Dutchess-Cossayuna-Nassau Areas

Geographic setting.—Dutchess, Cossayuna, Nassau, and associated soils are in the Slate Belt which averages about 50 miles in width and extends from northwestern New Jersey to western Vermont. It is in the Valley and Ridge province of the Appalachian Highlands. The country ranges from undulating to rolling, ridgy, or mountainous. Much of the rougher, steeper, or stonier land is in forest or pasture, whereas better areas are cultivated.

Climate.—Cool-temperate and humid. Summers are moderate or cool; winters, cold. Frost-free season 140 to 170 days.

Vegetation.—Forest of white and red oak, birch, maple, beech, and white pine.

Parent materials.—Weathered blue-gray slate interbedded in places with limestone and sandstone, and glacial till and outwash derived from those rocks.

Soils.—Dutchess, Bernardston, Newport, and Nassau soils are developed on slate and are well-drained and acid in reaction. Dutchess soils include silt loam and shaly, gravelly, and stony loams. Forested soils have beneath the thin forest litter a thin (3-inch) layer of dark-brown surface soil, grading in turn into a grayish-brown floury material of about the same thickness, and a firm but friable yellowish-brown subsoil, changing at about 18 inches to pale yellow. Below 24 inches is unaltered greenish-gray gritty till extending to bedrock at 3 to 6 feet below the surface. Newport soils are developed from deep, friable till comparatively free from stone and gravel. They are more productive than most other soils of the region. Bernardston soils are similar to the Dutchess, but developed from deeper and heavier till. Nassau soils are shallow over bedrock, excessively drained, and droughty.

Cossayuna, Troy, Albia, and Boynton soils are developed on gravelly till from slate, limestone, and sandstone. They are acid soils, but the acid condition is modified by limy materials of the substratum. Cossayuna soils are similar in profile to the Dutchess, except that the substratum below 36 inches is a greenish-gray alkaline compact till to bedrock at 4 to 10 feet. Drainage is good. Troy soils on steep drumlins have very compact substrata but are well-drained. Albia soils on smoother drumlins have a hardpan at 2 feet. Boynton soils, on nearly flat to gently sloping land are imperfectly drained and have dark surface soils and alkaline substrata within 2 feet of the surface.

Hoosic and Copake soils are developed on terraces. The surface soils are brown, underlain by yellow-brown mellow subsoils merging into substrata of gravel and sand at 2 to 3 feet. Hoosic soils are acid throughout, whereas the Copake are alkaline in the deep substrata. Schodack soils are similar to the Copake but are developed on kames and have a hummocky surface.

Use.—Large areas of Dutchess, Bernardston, Newport, and Nassau soils are in forest, though areas having smoother surface and finer textured soils are cleared

and used for timothy, clover, oats, buckwheat, corn silage, orchards, and pasture. Cossayuna soils are largely cleared and used for dairy farming, orcharding, and market gardening. Alfalfa is the most important crop. Troy and Albia soils are used for similar purposes, but are not so well suited to alfalfa. Boynton soils are used mainly for hay. Hoosic and Copake soils are used for the common crops of the region. Schodack soils are on rough land and are little used for crops.

Erosion is active on rougher and steeper lands and these should be carefully handled or kept in grass or forest. Use of manure and complete commercial fertilizers is essential to good production of most crops upon these soils.

Everett-Alderwood Areas

Geographic setting.—Everett, Alderwood, Kitsap, and associated soils occur mainly in the Puget Sound Basin, and the similar Loon, Waits, Kootenai, and associated soils in northeastern Washington, northern Idaho, and northwestern Montana. They occupy glacial terraces and undulating to steeply rolling or hilly areas with associated bogs, lakes, and drainage courses, and wide, flat stream valleys with steep marginal slopes.

Climate.—Mean annual rainfall in Puget Sound areas is 25 to 60 inches, with cool dry summer periods, mild wet winters, and light snowfall; the average frost-free season ranges from about 150 to 210 days. In northeastern Washington, Idaho, and Montana areas precipitation is 25 to 40 inches, with heavier snowfall and frost-free season of 90 to 120 days.

Native vegtation.—Coniferous forest of fir, pine, and hemlock, with cedar, alder, and undergrowth of salal, Oregon-grape and possibly other species of holly-grape, Oregon maple, ferns, and bracken in moist localities; mainly logged off.

Parent materials.—Glacial drift with included stratified glacial lake sediments and outwash materials derived from wide range of rocks.

Soils.—These are slightly acid, podzolic, or leached light-colored soils, having in some places a very thin, slightly developed, gray ashy layer beneath the dark organic surface layer. They are mostly gravelly sandy loams and stony loams, though there are areas of finer textured soils. They contain numerous small rounded reddish-brown or dark-brown shotlike aggregates cemented by oxides of iron and aluminum and containing phosphorus in unavailable form. The common soil profile is characterized by (1) loose forest litter; (2) a thin, dark-brown surface layer, (3) grayish-brown, pale reddish-brown, or yellowish-brown friable material; (4) subsoil of pale yellowish-gray or light-gray irregularly stratified, loose, porous, sandy and gravelly materials, with excessive drainage and low moisture-holding capacity. Alderwood soils have a siliceous cemented gray substratum or hardpan layer relatively impermeable to moisture and roots. Kitsap soils have a fine-textured pervious subsoil and good moisture-holding capacity.

Use.—Most of the land is cut-over or burned-over timberland growing up to second-growth forest, and the larger part is best suited to forestry and recreational uses. High cost of clearing, susceptibility to drought, and low inherent productivity all tend to discourage farming development. Cleared areas are used to some extent for dairying and general farming, but near the cities they are used more for growing berries, small fruits, and vegetables, raising rabbits and poultry, and suburban and subsistence home sites. Agriculture is developed mainly on the organic (peat and muck) soils and alluvial soils of the Puget, Bellingham, and other associated series.

Fairmount-Lowell Area

Geographic setting.—This area is shown on the map as one continuous body of land in northern Kentucky, southeastern Indiana, and southwestern Ohio; actually it is divided by the Ohio River. It completely surrounds the bluegrass region of Kentucky and is often called the outer bluegrass region. It is essentially a dissected plain, with much steeply sloping land, and local variation in altitude as much as 500 feet. The part north of the Ohio River has been glaciated, but the thin drift was eroded away to expose the formations which form the parent materials of the Fairmount-Lowell area. Elevations range from 500 to 1,000 feet above sea level.

Climate.—Continental; summers are long and warm; winters moderately severe, with much freezing and thawing. Average annual rainfall ranges from 40 to 45 inches, about equally distributed throughout the year. Severe spring and sum-

mer droughts at times seriously lower crop yields and reduce pasturage. The average frost-free season ranges from 180 to 190 days.

Native vegetation.—Hardwood forest with many species; white oak, hickory, sugar maple, and walnut prominent northward; chestnut oak, bur oak, tuliptree (yellow poplar) southward.

Parent materials.—Generally thin residuum from thin-bedded limestones and gray shales, in places phosphatic. The shales are for the most part calcareous in varying degree.

Soils.—The character of the parent materials and bedrock, the proximity of a great master stream, and the high rainfall have resulted in thorough dissection of the area. This has resulted in a hilly terrain, with steep slopes, V-shaped valleys, narrow ridge tops, and shallow soil materials over most of the area. Where the thin parent material is highly calcareous, soils of the Fairmount series have been developed. These soils are Rendzinas and have a very dark gray granular clay surface soil, high in organic matter, and a yellow or dull-gray clay subsoil which grades downward to calcareous shales or thin-bedded limestone at a depth of less than 2 feet. Thin fragments of limestone are scattered over the surface. The soil is alkaline or calcareous throughout. Associated soils are Salvisa and Eden, both shallow soils of the hillsides, but with less organic matter, in many places less lime, and in general more severely eroded. The Lowell soils are developed from more deeply weathered parent materials, generally on the more gentle slopes. The surface soil is light grayish-brown silt loam or silty clay loam; the subsoil yellow or mottled yellow and brown, stiff, smooth silty clay to a depth of 3 or 4 feet; the bedrock material is clay shale with variable lime content. Switzerland silt loam and Shelbyville silt loam are similar soils but developed from acid residual materials of much greater thickness. The associated soils in the bottom lands, of the Huntington and Lindside series, are generally very fertile, agriculturally important out of proportion to their total area.

Use.—Generally, small farms predominate and the rural population is dense. The unfavorable relief is compensated for in part by the relatively high fertility of the soils. These two factors, dense population and good soil, lead to the use of unusually steep lands for cultivated crops, chief of which are corn and tobacco. Alfalfa is grown successfully on some of the calcareous soils. Much of the land is in pasture. Kentucky bluegrass is an important pasture grass. Fields temporarily out of cultivation grow up to brush and small trees, of which black locust and red cedar are important species.

Hagerstown-Frederick Areas

Geographic setting.—Hagerstown, Frederick, and associated soils occupy a number of areas, the largest of which comprises the great valley of Virginia and extends across Maryland and for a considerable distance into Pennsylvania and northeastern Tennessee. Other areas are in southern Missouri, central and western Kentucky, southern Indiana, and West Virginia. The land is undulating, gently rolling, rolling, or strongly rolling. Drainage is good through perennial streams and numerous sinks. There are many caverns and underground streams.

Climate.—Temperate and healthful; winters moderately cold. At Ephrata, Pa., mean temperature is 51° F., mean rainfall 41 inches, snowfall 33 inches, frost-free season 165 days; whereas at Lexington, Va., mean temperature is 54°, rainfall 40 inches, snowfall 21 inches, growing season 176 days.

Native vegetation.—Greater part cleared of original growth of hardwoods. Some of the stony and steeper areas have a growth of locust, white oak, and hickory.

Parent materials.—Limestone, dolomitic limestone, and some shale. In places the limestone is very cherty.

Soils.—Dominantly silt loams and clay loams in texture. They contain a fair amount of organic matter and mineral plant nutrients and are medium to strongly acid in reaction. Hagerstown soils predominate in Pennsylvania, Maryland, and northern Virginia. They have brown surface soils and reddish-brown, moderately heavy but permeable subsoils. The Federick soils are the dominant soils from a few miles southwest of Winchester, Va., southwest through the valley to Wytheville. They differ from the Hagerstown in having light-brown to dark-yellow soils and light-red to yellowish-brown subsoils. The Dunmore soils in southwestern Virginia are light gray and grayish yellow and the subsoils are yellow to brownish yellow. Areas of light-gray soil and yellow subsoil with a high con-

tent of cherty material and also areas of brown soils underlain by brownish-yellow subsoils are of frequent occurrence. In central Kentucky the cherty limestone has given rise to very stony or gravelly soils. The Duffield soils are important in Pennsylvania.

Use.—The greater part of these areas is farmed or in pasture. This is a region of prosperous farmers and good houses and barns, and the land use is well adjusted to soil conditions. A good to high standard of living and a self-supporting agriculture are maintained. The principal crops in Pennsylvania and Maryland are wheat, corn, hay (timothy and clover), oats, potatoes, and tobacco; and these crops, with the exception of tobacco, prevail throughout the greater part of the valley. Apples are an important commercial crop in northern Virginia. These find markets in this country and England. In southwestern Virginia, cattle raising is the main industry. Throughout the entire section dairying and fattening of beef cattle afford considerable income. Sheep, cattle, and hogs are raised. Most of the pasture is on the stony or more sloping areas.

Helmer-Santa-Benewah Areas

Geographic setting.—The Helmer, Santa, Benewah, and similar and associated soils occur mainly in northern Idaho, western Montana, Wyoming, Colorado, and in the Sierra Nevada in California, with smaller outlying areas in eastern Washington, New Mexico, and Arizona. With these are included a number of related soils not yet identified and mapped. They occupy upland benches and rolling or hilly to mountainous areas of 2,000 to 5,000 feet elevation in the northern areas and extending to elevations of 10,000 or more feet in the southern areas where they occupy steep slopes and ridges below mountain crests of rough stony land having little or no soil cover. They are associated at the lower elevations in California with the Aiken soils and in northern Idaho and eastern Washington with the Palouse and the Underwood soils. Most of the areas are heavily forested, difficult of access, and thinly populated.

Climate.—Average annual rainfall of 20 to 40 or more inches; summers comparatively dry; heavy snowfall, severe winters, and short growing season, usually less than 90 days.

Native vegetation.—Coniferous forest, mainly species of pine, fir, hemlock, and spruce.

Parent materials.—Mainly bedrock of granite, schist, quartzite, argillite, basalt, and rhyolite, with superficial covering of loess in places.

Soils.—Light-brown to brown soils with thin to thick surface layer of forest litter, and feebly developed ashy-gray podzolic layer in sheltered and more heavily forested areas. Usually of granular or single-grain floury structure. Helmer and Benewah soils have subsoils of yellowish-brown to light grayish-brown becoming more compact and grayer below. Santa soils have a thick gray ashy layer overlying brown, dense, and columnar material, with much organic staining. Santa soils are developed on the smoother and flatter surfaces. Soil profiles are weakly developed in steeper areas of excessive drainage and subject to erosion. Soil materials are mildly to strongly acid in reaction.

Use.—Some of the lower lying areas are used for grain, hay, and general farm crops, but most of the land, because of its steep or rough surface, adverse climate, and isolation, is mainly unsettled and uncleared of timber and stumps and has its best economic use for forestry, summer home sites, and recreation.

Lordstown-Volusia Area

Geographic setting.—Lordstown, Volusia, and associated soils occupy a large area in southern New York and northern Pennsylvania on the northern end of the Appalachian Plateau, a high smooth-topped plateau, cut by fairly wide steep-sided valleys. The plateau level averages about 2,000 feet and the valley floors about 1,000 feet above sea level. Glacial till is thin on the plateau and upper valley walls and thick in the valleys. Much of the smoother, less stony land is under cultivation or in pasture, but large areas of steeper, stonier, or poorer lands are in forest. The country is not so prosperous as the Ontario-Honeoye areas to the north.

Climate.—Cool-temperate and humid. Precipitation 30 to 40 inches. Summers, rather short and moderate or cool. Winters, long and cold. Frost-free season 120 to 150 days.

Native vegetation.—Forest of maple, birch, oak, white pine, and hemlock. Pastures contain spirea, hawthorn, and poverty grass.

Parent materials.—Glacial till from gray sandstones and shales, with limestone in places.

Soils.—Lordstown, Bath, Wooster, and Lansing soils are well-drained. Lordstown soils are on shallow till, of sandstone and shale materials, upon the plateau and side walls of the valleys. They are mostly gravelly or stony silt loams. The soils to about 4 inches are dark yellowish-brown and mellow, underlain by yellowish-brown, firm but friable material of similar texture, becoming paler with depth. At about 24 inches this grades into gray, slightly compact till, resting at about 36 inches on sandstone bedrock. There are many fragments and slabs of sandstone throughout the soil. Bath soils are similar to the Lordstown but are on deeper sandstone till on the undulating plateau. Wooster soils are on deep valley till and have gently to strongly rolling surfaces. Lansing soils lie along the northern edge of this belt where it adjoins the limestone areas. The soils

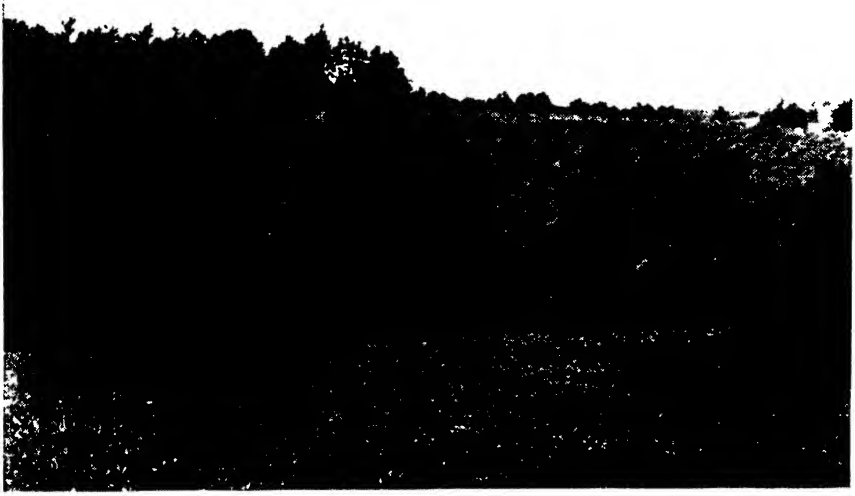


FIGURE 7.—A good yield of hay on Volusia silt loam, Steuben County, N. Y. This soil is much better adapted to hay than to cultivated crops, as the hardpan prevents good internal drainage and the land is cold and wet most of the year.

are acid but the parent material is calcareous. These are among the most productive soils in the area.

Volusia, Fremont, Erie, Chippewa, Mardin, Canfield, and Langford are poorly or imperfectly drained soils. They are characterized by hardpan. Volusia soils are on poorly drained gentle slopes or benches (fig. 7). The topsoils to an average depth of 7 inches are grayish-brown and mellow and pass into a pale-yellow, friable subsoil that is mottled with gray below 12 inches. At 18 inches lies a hardpan—blue gray mottled with yellow and brown—which merges below 24 inches into a blue-gray compact till. The profile is acid throughout. Fremont soils on flat plateau tops are similar to the Volusia but have more friable subsoils. Erie soils are similar to the Volusia but have slightly darker topsoils and more alkaline substrata. Chippewa soils, occupying depressions, have dark-colored surface soils and mottled gray and yellow subsoils. Mardin, Canfield, and Langford soils are somewhat better drained than the Volusia, have an undulating to rolling surface, brown topsoils, yellow-brown subsoils mottled with gray and yellow at about 18 inches, and a hardpan at about 24 inches. Mardin soils are on

shallow till from sandstone; Canfield soils, from deep valley till of sandstone and shale; and Langford soils, from alkaline till.

Chenango and Howard soils lie on terraces. They have brown, mellow topsoils, yellow-brown, friable subsoils and gravelly substrata below 20 to 30 inches. Both are productive soils. Howard soils have calcareous substrata at 3 to 6 feet.

Tioga, Middlebury, and Holly soils lie on bottom lands subject to overflow and are inherently fertile. Tioga soils are well-drained; Middlebury, imperfectly drained; and Holly, poorly drained.

Use.—Common crops are timothy, clover, oats, buckwheat, corn for silage, and potatoes. Lordstown soils are about half in crops and pasture, the remainder in forest. Yields are low unless land is fertilized. Bath soils are largely used for farming, being especially suitable for potatoes. Wooster soils are mostly cleared and are used for common crops. Yields are good under dairy-farming practices. Lansing soils are highly productive of the common crops of the area and also of alfalfa. Volusia and Fremont soils are used for hay, oats, and pasture. Yields are low. Erie soils are considered good for grass. Chippewa soils are largely in forest. Where drained they are used for hay, oats, and pasture. Mardin, Canfield, and Langford soils are used for timothy, clover, oats, buckwheat, silage corn, and potatoes. Yields are fairly good. Chenango soils are productive of the common crops of the region where properly farmed and respond readily to fertilization. The Howard soils have similar productivity and are also suitable for alfalfa.

Tioga, Middlebury, and Holly soils, though inherently productive, are subject to overflow, and crops are limited to corn, oats, hay, and pasture.

Miami-Crosby-Brookston Area

Geographic setting.—This area forms the heart of a farming country of central Indiana and west-central Ohio, often called the Little Corn Belt. The soils are not so consistently fertile as those of the prairie Corn Belt of Iowa and Illinois, but there is an association of fairly good light-colored, moderately productive soils and dark-colored, very productive soils which, with a favorable climate and relief, provides the physical basis for a prosperous, stable agriculture.

Climate.—Continental, with wide annual ranges in temperature. The winter temperature ranges down to −30°, the highest summer temperature up to 108° F. A winter minimum of −20° and summer maximum of 100° are attained in many years. The average frost-free period is about 160 days.

The average annual precipitation is quite uniform over the area, ranging from 35 to 40 inches, about half of which falls in the warm season from April to September. Summer droughts at times reduce crop yields and materially affect pastures.

Native vegetation.—The original growth was a deciduous hardwood forest, with white oak and sugar maple prominent on the well-drained Miami soils; beech and sugar maple on the Crosby soils; elm and basswood on the poorly drained areas of Brookston and on Clyde soils. Ground cover was generally thin and grass meager except in a few small open glades, which were for the most part wet lands.

Parent materials.—The parent materials are quite uniformly calcareous glacial drift, for the most part deposited as glacial till of medium to heavy texture. The water-laid drift is largely calcareous gravel; the recent alluvium is composed chiefly of silts and clays, which form fertile bottom lands.

Soils.—The upland soils of the region are complexly intermingled, due to the complexity of the micro-relief, which in turn produces an intricate intermingling of small areas of variable drainage conditions. This complexity of soil pattern is illustrated by figure 8.

The characteristic well-drained soil, though not dominant in area, is Miami silt loam. The plowed surface soil consists of friable grayish-brown silt loam, to a depth of 6 or 8 inches. The subsoil is brown or yellowish-brown silty clay, moderately pervious due to its nutlike structure; the substratum below an average depth of 30 inches consists of calcareous glacial till and extends downward for many feet.

Miami silt loam is well drained, readily maintained in good tilth, moderately fertile and responsive to good management. Crosby silt loam is an associated soil developed from similar parent material, on more nearly level areas. Owing

to imperfect drainage and a fluctuating but high average water table, Crosby silt loam has a grayer surface soil and a mottled, heavier, and less pervious subsoil than Miami silt loam. It is consequently less productive, until it is drained, limed, and fertilized. Brookston silty clay loam is associated with the Miami and Crosby soils, occupying the shallow sags and swales characteristic of the glacial till plain. Developed under poor drainage with preservation and incorporation of organic matter, the surface soil is darker grayish brown to a depth of 8 to 12 inches. The subsoil is gray and yellow mottled silty clay, the deeper substratum below 40 inches is calcareous glacial till. The Brookston soils are rich in organic matter and plant nutrients. After drainage, which is necessary for ordinary production, it becomes the most productive soil of most of the farms of the area. Important soils associated generally with Miami-Crosby-Brookston are the Fox soils, similar to Miami but occurring on stream terraces and plains and underlain by gravel, and Genesee and Eel series, fertile soils of the first bottoms, the former well drained, the latter imperfectly drained. The south portion of the Miami-Crosby-Brookston area is similar in general aspect and soil features, but owing to greater geologic age of the parent glacial drift the soil materials are more thoroughly weathered. The Russell soils, otherwise similar to Miami, have thicker surface

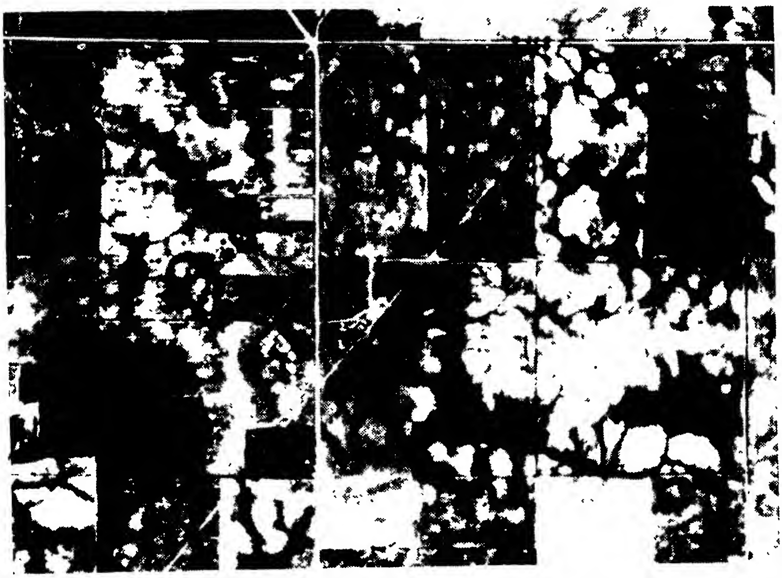


Figure 8.—Vertical aerial photograph covering about 420 acres in Randolph County, Ind., showing complexity of the soil pattern. Light-colored areas are of Crosby silt loam and dark-colored areas of Brookston silty clay loam.

soils and thicker but somewhat more pervious subsoil, with a total depth to calcareous parent glacial till of about 4 feet. Fincastle silt loam is similarly analogous to Crosby silt loam.

Use.—While corn is the dominant crop and hogs are the chief element in livestock production, the agriculture is on the whole quite diversified and the natural conditions are such as to favor further diversification when and where economic conditions warrant it. The physical features of the area are favorable to a diversified and if necessary self-sufficing type of agriculture. Wheat, oats, and hay crops are important throughout the area; a section centering in Preble, Darke, Miami, and Montgomery Counties, Ohio, is an important tobacco-growing center; practically every county of the area produces potatoes, most farmers have gardens and small orchards, and woodlots form part of practically every farmstead in the region. Beef cattle, dairy cows, and poultry are raised to some extent on the majority of the farms.

Miami-Kewaunee Areas

Geographic setting.—There are two important Miami-Kewaunee areas, one in southern Michigan, extending southwestward into northern Indiana, the other in eastern Wisconsin, extending southward into northern Illinois. Both are part of the glaciated region of the Lake States, in general a plain of variable and complex local relief. The surface is largely as left by the last glaciation and consists of roughly rolling or hilly moraines, undulating till plains, with marked depressions, nearly level outwash plains, and old lake beds. The stream pattern is erratic, scarcely developed at all, much land is poorly drained, and there are numerous lakes, ponds, and bogs.

Climate.—Continental, humid, modified by the Great Lakes. Average annual precipitation, 30 to 35 inches, 50 to 60 percent normally falling in the warm season. Summers generally warm, except near Lake Michigan, with temperatures ranging at times above 100° F. Winters are moderately severe, with much snow, temperatures falling to −20° or lower each winter. Average period free from killing frosts, 170 days near Lake Michigan, 130 days inland in Michigan.

Native vegetation.—Deciduous forest, chiefly white oak, sugar maple, beech; some white pine and hemlock in places. On associated wet lands are elm, ash, soft maple, willow, and tamarack.

Parent materials.—Glacial drift of late Wisconsin age, mostly calcareous till of medium texture. The drift materials in western Michigan and much of that in Wisconsin have a reddish or pinkish hue, elsewhere they are gray. There are included sandy noncalcareous materials, very heavy clays, and deposits of peat.

Soils.—The soil pattern is generally complex, owing to the intimate mixture of parent materials and the wide variation in drainage conditions within small areas. Miami loam is a representative well-drained soil of the area in south-central Michigan. The cultivated surface soil is grayish-brown loose friable loam to a depth of 8 inches. The brown subsoil is distinctly heavier in texture, but permeable to water and plant roots, owing to its nutlike structure. The substratum material is medium-textured, moderately friable glacial till, rich in lime below a depth of 2½ or 3 feet. The surface soil and upper subsoil are somewhat acid. The Hillsdale soils, associated with Miami on undulating to rolling uplands, differ in being developed from more siliceous material, having a yellow subsoil, and in greater depth to lime (4 or 5 feet). The Conover soils of the same region occur on flatter, lower situations, have imperfect drainage and gray or dark-gray surface soil and mottled subsoil. The substratum is glacial till like that beneath Miami. The Brookston soils are very dark colored Half Bog soils associated with the Miami. They are rich in organic matter and practically all plant nutrients, and when drained are very productive, suited to corn, oats, sugar beets, and hay. Westward in the area in Michigan and across the lake in Wisconsin is the reddish glacial drift which forms the parent material of the Kent, Isabella, Kewaunee, and Superior soils. These soils differ visibly from Miami soils in their reddish or pinkish hue. The Kewaunee soils of Wisconsin are very similar to Miami except for this color difference and are about equally productive; the Kent soils of Michigan and the Superior soils of Wisconsin are developed from heavier parent materials and have less drainage. The Isabella soils are generally somewhat looser and lighter in texture with more gravel and stones than Miami loam. Lime is less abundant, particularly in the sandy loam type, and the soils are slightly less productive under equivalent conditions of relief and management.

The Poygan soils are poorly drained dark-colored soils associated with the Kewaunee and Superior soils. Other soils throughout the Miami-Kewaunee area are: Very sandy soils such as Coloma and Plainfield (described elsewhere); Bellefontaine and Fox, both underlain by calcareous gravels, the former on rolling and rough lands, the latter on nearly level plains; muck and peat.

Use.—The better lands of this area are suited to a permanent, prosperous agriculture, based upon corn, small grains, hay, and pasture, and the feeding of hogs, cattle, and sheep and the production of milk. The well-drained soils, such as Miami loam, are only moderately fertile but are generally responsive to good management; the associated poorly drained mineral soils are both fertile and responsive. The included sandy lands are generally less fertile, but in places are used for vegetables and fruits. Under such use, commercial fertilizers are important for special crops, such as onions, celery, mint, lettuce, and cabbage, and for hay. Sugar beets are an important crop on the poorly drained, dark-colored soils in parts of Michigan.

Muskingum-Wellston-Zanesville Areas

Geographic setting.—The lands characterized by the Muskingum, Wellston, and Zanesville soils occur as three bodies of sufficient size to indicate on the generalized soil map: (1) A large irregular area, centering to the southward in eastern Kentucky, with one arm reaching northeastward through western Virginia and central West Virginia into southwestern Pennsylvania, the other extending northward through southeastern Ohio; (2) a smaller area in western Kentucky and southern Indiana; and (3) a very small area in south-central Indiana. The eastern area forms a portion of the lower dissected Appalachian plateaus; the smaller western areas are parts of the Interior Low Plateaus which lie south of the glaciated region. The relief varies with the degree and character of dissection, from rough hilly or mountainous with very steep slopes, narrow ridge tops and valleys, to smoothly rolling, with short gentle slopes, broad ridge tops, and wide valley floors. The elevations above sea level range from 500 feet or less in western Kentucky to 1,500 feet or more in the eastern area.

Climate.—Average annual precipitation ranges from 40 to 50 inches, about half of which falls in the growing season. Temperatures vary with the latitude and altitude. The summers are hot and long in western Kentucky and southern Indiana, with temperatures often above 100° F. They are definitely cooler and shorter in the northeastern part of the eastern area. Winter temperatures fall below −25° at times over practically all of the three areas. The growing season ranges from 150 days in the northeastern higher lands to 190 days in western Kentucky.

Native vegetation.—Deciduous forest, with oaks dominant.

Parent materials.—Residuum from sandstones, siltstones, and shales, of varying depths and physical composition. On more nearly level ridge tops in the western areas, and in places in eastern Ohio, the unconsolidated soil material ranges up to 10 feet in depth; on steep slopes it may be less than 2 feet, with rock fragments throughout.

Soils.—The dominant soil types of the areas are grouped in the Muskingum series, shallow soils developed from sandstone-shale residuum. Under forest cover they are marked by a very thin covering of loose forest litter; a dark grayish-brown layer of humus soil, less than 2 inches thick; a light grayish-yellow loose friable mineral soil, generally acid, 4 to 8 inches thick; a layer of mixed fine earth and rock fragments of varying thickness and texture which extends to a depth of 1½ to 2½ feet; bedrock of sandstone, siltstone, or shale. Rock fragments occur on the surface and through the soil. The Muskingum soils occur on the steeper slopes in all parts of the area. Northward these soils merge with the Gilpin soils, with definitely darker surface soils; southward with the Hanceville soils, with reddish subsoils; and at higher altitudes with the Dekalb soils, which exhibit some features of the Podzol profile. The Wellston soils are similar in source and composition of parent materials to the Muskingum soils, but occur on gentle slopes where the residuum has accumulated to greater depths and where there has been sufficient time for the development of the characteristic normal soil of the region. The surface soil, under cultivation, is grayish-brown, generally friable silt loam or loam to a depth of about 8 inches. The subsoil is definitely heavier, with a nutlike structure, penetrable by moisture and plant roots; the substratum to a depth of about 3 or 4 feet is a mixture of fine earth and fragments of shale or sandstone, grading to bedrock below. The Zanesville soils occur where the mantle of weathered fine earth material is 4 to 10 feet thick; they are similar to Wellston in the upper layers, but have a definite layer of stone-free silt and clay between the subsoil proper and bedrock. On the broader upland divides where the land is nearly flat, particularly in southern Indiana and western Kentucky, drainage is restricted, and soils similar to Zanesville, but mottled below a depth of 18 or 20 inches, have been developed. Such soils are mapped as Tilsit silt loam. The soils of the associated stream terrace lands are chiefly of the Holston, Monongahela, and Tyler series; the soils of the first bottoms are Pope, Philo, and Atkins, in order of good to poor drainage. The soils of uplands, stream terraces, and first bottoms are characteristically acid throughout.

Use.—The lands of these areas, particularly the Muskingum soils, are chiefly in timber, mostly cut over, and of wide range in present value. Some areas are in brushy pasture of poor quality. There has been much erosion on cleared lands; many fields are abandoned or temporarily idle. The deeper soils of the uplands, such as Wellston and Zanesville, are only of medium quality as crop-

land, but have been used for corn, hay, and small grains, and to a less extent for tobacco, particularly in Kentucky. When farmed these lands need lime and complete commercial fertilizers for good production of crops. There are many sections where cropping is largely confined to the stream terraces and bottom lands.

Ontario-Honeoye-Pittsfield Areas

Geographic setting.—Ontario, Honeoye, and associated soils occupy rolling lands in central and northern New York. The main belt is about 25 miles wide and 300 miles long east and west, and lies north of the Appalachian Plateau. The hills rise 500 to 800 feet above sea level and 200 to 500 feet above the lake plain. Most of the land is cultivated and supports a varied and thriving agriculture. Small wood lots are the only remnants of the former luxuriant forest cover. The Pittsfield and associated soils occupy a narrow belt in western Massachusetts, eastern New York, and adjoining sections of Vermont and Connecticut. They are somewhat stonier and have larger areas of forest and pasture.

Climate.—Cool-temperate and humid. Summers, moderate or cool; winters, long and cold; precipitation, 30 to 45 inches. Frost-free season 150 to 160 days.

Native vegetation.—Heavy deciduous forest including oaks, maples, beech, hickory, ash, birch, butternut, white pine, arborvitae, and alder.

Parent materials.—Glacial till from limestone, with calcareous shale, slate, sandstone, and quartzite in places. Also outwash from till.

Soils.—These soils are commonly medium to dark brown in color and have lighter brown, grayish-brown, or yellowish-brown subsoils. Soils are normally acid but substrata are calcareous. The Ontario soils have surface soils averaging about 4 inches thick, dark brown, mellow, friable, and having a soft crumb structure. The upper subsoil is a lighter grayish to yellowish-brown material, firm but friable, and tinged with red in places. Below about 36 inches the material is somewhat heavier; and below about 48 inches lies the reddish or pinkish-gray rather compact calcareous sandy till. The surface is undulating to rolling and drainage is good. Honeoye soils are developed from more limy, less siliceous till. They are somewhat similar to the Ontario but have the gray calcareous till at about 24 inches. Farmington soils have developed on shallow till over limestone, rarely deeper than 2 feet. They are droughty soils and some areas are very stony. Hilton soils are developed on deep till in smooth, gently sloping areas. They have a gray subsoil over hardpan at about 2 feet. Mohawk soils are rather shallow soils over black calcareous shale. Lyons soils occupy small, poorly drained depressions, have dark surface soils, mottled subsoils, and gray substrata.

Pittsfield soils have brown mellow surface soils resting on a yellow-brown, firm but friable subsoils grading through pale yellow-brown material to the slightly compact, gray, slightly calcareous till at about 36 inches. Some types are quite stony. Drainage is good.

The Stockbridge soils have very compact blue-gray, highly calcareous substrata containing much slate. Drainage is good. Madrid soils contain quartzite gravel and boulders, are leached to greater depth, and are more acid than most associated soils. Dover soils, on till from crystalline limestone and marble, are fluffy brown soils resting on gray raw till at about 2 feet.

Palmyra and Alton soils are on terraces and have gravelly calcareous substrata. The surface is fairly flat but drainage is good. The Palmyra soils are dark brown, have lime at about 20 inches, and are very productive. The Alton soils are lighter colored, more siliceous, more deeply leached of lime, and less productive.

Soils of the bottom lands include the Genesee, Eel, and Wayland. They are subject to overflow, are mainly silt loams, and have a slightly alkaline reaction. Genesee soils are well drained and highly productive; Eel soils are imperfectly drained; and Wayland soils are poorly drained.

Use.—Ontario, Honeoye, and Mohawk soils are nearly all under cultivation and are used for timothy, clover, alfalfa, wheat, oats, potatoes, tomatoes, cabbage, beans, apples, and pasture. Under the prevailing system of dairy farming supplemented by special crops and fruit, they are very productive. Farmington soils are used largely for pasture and hay; Hilton soils, for hay and small grains; and Lyons, for hay, pasture, and forest.

Pittsfield soils are mostly farmed. Timothy, clover, alfalfa, and pasture grasses yield well. Stockbridge soils yield good crops of timothy, clover, and

other common crops of the region. Madrid soils are valuable largely for pasture. Dover soils support good bluegrass, clover, and alfalfa. Palmyra soils are practically all cultivated and are highly productive under a dairy farming and special crop system. Among the special crops are beans, cabbage, potatoes, and tree fruits. Alton soils are less productive.

Genesee soils are productive of corn, oats, and hay. Eel soils are used mostly for hay and Wayland soils largely for pasture.

Erosion is a serious problem on many of the steeper areas and most such lands should be kept in forest or pasture.

Olympic-Melbourne Areas

Geographic setting.—The Olympic, Melbourne, and similar and associated soils occupy extensive hilly and mountainous areas in western Washington and Oregon and northwestern California, the Olympic soils dominating the western slope and foothills of the Cascade Mountains at elevations of 500 to 5,000 feet and the Melbourne the Coast Range from sea level to 3,000 feet. They are associated in the Cascade Mountains with areas of rough stony land dominated by rugged and snow-capped peaks, on the east with the Underwood soils, and on the west at the lower elevations with the Aiken and the Willamette, Amity, and other soils of the Willamette Valley. They occupy moderately to steeply sloping land entrenched by canyonlike river valleys and with areas of shallow, stony soils and abrupt cliffs. The coastal Melbourne areas are of somewhat smoother and more subdued topography.

Climate.—Humid, with rainfall of 40 to more than 80 inches in the Cascade Mountains and in excess of 100 inches in part of the Coast Range, most of which occurs during the fall, winter, and spring months. Fogs are frequent in the coastal areas. Snowfall is heavy at the higher elevations. The growing season ranges from more than 200 days along the coast to less than 90 days in the higher altitudes.

Native vegetation.—Coniferous forest dominated by fir, hemlock, and spruce with dense undercover of shrubs, vines, and bracken, and with alder and cedar in the moister localities.

Parent materials.—Basaltic and andesitic rocks and volcanic tuffs giving rise to the Olympic, and shales and sandstones giving rise to the Melbourne soils.

Soils.—Dark-brown friable surface soils beneath a superficial layer of forest litter, becoming rich brown below and grading into moderately compact plastic subsoils, yellowish and mottled with reddish brown in the Melbourne and brown to reddish brown in the Olympic. Clay loam and loam textures predominate. Soils and subsoils moderately to strongly acid in reaction.

Use.—Mainly forestry and grazing with lower areas utilized for walnuts, orchard fruits, and berries, and to a limited extent for general farming purposes. The dominant areas are steep or rough, heavily timbered, logged off or burned over, difficult to cultivate without loss of soil by erosion, sparsely settled, and best utilized for forestry and recreational activities.

Porters-Ashe Areas

Geographic setting.—The Porters-Ashe soil areas comprise the nationally known Blue Ridge and Great Smoky Mountain areas of Virginia, North Carolina, South Carolina, Tennessee, and Georgia. They separate the Piedmont on the east from the great valley of Virginia and Tennessee on the west. Topography comprises mountain ridges, knobs, and long steep mountain sides. Elevations range from 1,500 to 6,000 or more feet. In western North Carolina rises the highest peak in the eastern United States. This is Mount Mitchell, with an elevation of 6,711 feet. The area is well to excessively drained and in places streams have cut deep valleys and gorges with steep to almost perpendicular walls. There is little erosion, owing to the friable consistence of the soils and subsoils and to the protection of trees and grasses.

Climate.—In many places somewhat similar to that in Maine—cool, invigorating, and healthful. Long cold winters; pleasant summers. Mean annual temperature ranges from 49° to 54° F., mean annual rainfall from 54 to 41 inches, snowfall, 9 to 44 inches. Average frost-free season about 170 days. On some of the highest mountains frost may occur practically every month.

Native vegetation.—Dominantly hardwoods—red, white, and post oak, hemlock,

white balsam, walnut, black locust, hickory, ash, basswood, sugar maple, table mountain pine, beech, dogwood, and sourwood. Undergrowth in many places, of rhododendron, laurel, ferns, and huckleberry.

Parent materials.—Granites, gneisses, schists, and some dark-colored basic rocks.

Soils.—Characterized by friable consistence of soils and subsoils, small mica scales, a relatively high content of organic matter, and medium acid reaction. Porters soils have brown surface soils and yellowish-brown to reddish-brown friable clay loam to clay subsoil. Ashe soils have gray to light-brown surface soils and yellow friable clay loam to clay subsoils. The broken bedrock mixed with clay material lies 3 to 5 feet below the surface. Included soils are the Talladega, Chandler, Fannin, Halewood, and Hayesville series, derived from mica schist, silty in character and containing large quantities of small mica scales. Extensive areas of rough stony land are of frequent occurrence. There are comparatively small areas of alluvial soils highly prized for growing corn and hay crops.

Use.—Soils are inherently fertile but the climate affects crop adaptation and steepness of slope restricts cultivation. Large areas are in bluegrass and used for pasture. There are several commercial apple orchards. Main cash crops are corn, wheat, tobacco, buckwheat, cabbage, onions, potatoes, pumpkins, and garden vegetables. Farmers do not have a large cash income but sell some cattle, apples, cabbage, potatoes, tobacco, and forest products. A self-sufficing agriculture is practiced. Some revenue is derived from the sale of timber, pulpwood, bark for tannic acid, and medicinal herbs and galax leaves. Large areas are forested, with considerable acreage in national forest. It is ideal summer-resort country, and attention is being directed toward its use for recreational purposes. It includes the Shenandoah and Great Smoky Mountains National Parks.

Plainfield-Coloma Areas

Geographic setting.—Plainfield, Coloma, and similar droughty sandy soils dominate a number of areas in the western Great Lakes region. Four such areas are of sufficient size to be shown on the generalized soil map. Smaller but locally important areas are scattered through southern Michigan and northern Indiana and elsewhere in the southern Great Lakes region. The surface features are variable, ranging from nearly level plains to roughly broken or choppy glacial moraines. The irregular relief of certain very sandy areas is due to dune formation. The elevation above sea level ranges from 580 feet to more than 1,000 feet.

Climate.—Average annual precipitation over most of the areas is about 30 inches, but there is marked variation in its distribution and effectiveness. The percentage occurring between April 1 and September 30 increases westward from 50 percent in southeastern Michigan to 70 percent in the area in eastern Minnesota. There is also significant variation in relative humidity; in general, it is higher near the Great Lakes. The Great Lakes have a moderating effect on temperatures. Near Lake Michigan the absolute maximum for the year is 101°, the minimum −21° F.; while in eastern Minnesota and central Wisconsin the extremes are greater. In southwestern Michigan, near Lake Michigan, the average frost-free period is 170 days; in central Wisconsin and eastern Minnesota it is 140 days.

Native vegetation.—Forest, with oaks dominant; trees generally small to medium in size, stands thin, particularly westward. Some white pine and jack pine northward.

Parent materials.—Very sandy glacial drift except in the western part of the area in central Wisconsin, where the sands have been accumulated by the weathering of sandstone formations. Much of the soil material has been shifted by water and wind. The dominant mineral throughout is quartz.

Soils.—Plainfield soils have light grayish-brown loamy sand surface soils to a depth of 6 or 8 inches; yellowish-brown sandy subsoils to 18 inches; with yellow to gray sands forming the substratum to depths of 10 feet or more. These soils occur on nearly level or undulating plains. Coloma soils are similar to the Plainfield except in their occurrence on rougher lands and in less definite assortment of the parent materials. Bridgman fine sand occurs on the dunes around Lake Michigan. Quartz sands weathered from sandstone form the parent materials of the Boone sands and fine sands in west-central Wisconsin. These soils are similar to Plainfield. The dry sandy soil of the area in east-central Minnesota is chiefly Zimmerman fine sand. The soil material is nearly all quartz sand, reworked by water and wind. Here there is an intimate association of peat and sandy Half Bog soils with the drier Zimmerman soils. This condition exists also

in central Wisconsin and to a less extent in southern Michigan and northern Indiana. The associated wet sandy soils are of the Newton, Maumee, and Saugatuck series.

Use.—These lands are for the most part marginal or submarginal cropland, owing to low average moisture-holding capacity and fertility. The drier areas are grown up to small timber and brush or are abandoned farm lands. Bog soils and Half Bog soils are used in places for onions, potatoes, celery, mint, and other special crops, and for hay and pasture. A section in southwestern Michigan is highly cultivated to tree fruits, small fruits, grapes, and vegetables. Here the advantages of climate (modified by Lake Michigan) and markets justify the use of commercial fertilizers and the intensive cultural methods necessary to the production of these special crops.

Penn-Lansdale Area

Geographic setting.—The Penn-Lansdale area embraces disconnected parts of the Piedmont from northern Virginia through Maryland to Pennsylvania and northern New Jersey. The land is smoothly undulating with occasional rolling or hilly areas to break an otherwise somewhat monotonous landscape. Well-tilled fields, large homes, and commodious barns give evidence of prosperity, but they are not so closely spaced as on the Chester and Hagerstown soils and the average size of farm must be greater to insure adequate income to the owner (fig. 9). Wooded

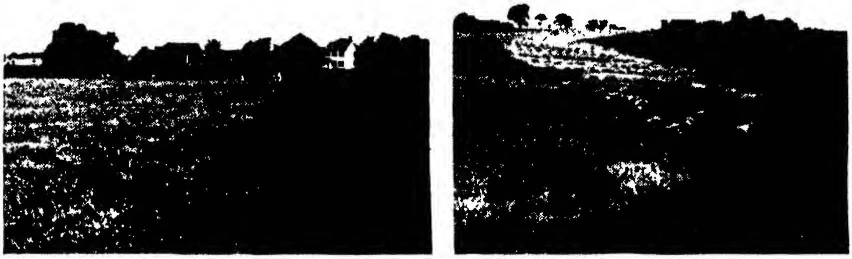


FIGURE 9.—Penn and Lansdale soils are used for general farming and dairying in northern New Jersey: *A*, Pasture and homestead on Penn soils; *B*, this good crop of wheat is characteristic.

areas are largely confined to steep slopes close to streams and to more or less stony soils associated with those of the dominant Penn and Lansdale series.

Climate.—Thirty-five to forty-five inches of precipitation, somewhat more than half falling during the average frost-free season of 160–195 days. Summers moderate to hot and humid; winters moderately cold, but short.

Native vegetation.—Deciduous forests, composed chiefly of white oak, hickory, beech, maple, and elm, with some cedar.

Parent materials.—Penn soils, Indian-red and purple-red Triassic shales and sandstones; Lansdale soils, yellowish-gray and gray shales and sandstones; Lehigh soils, dark-gray slates and sandstones; Montalto soils, trap (diabase rock).

Soils.—Penn soils have brown or purplish-brown silty and shaly surface horizons 6 to 10 inches thick, underlain by Indian-red or purplish shaly clays to 20 or 30 inches. Purplish or Indian-red moderately soft sandstones and shales comprise the parent rock. Lansdale soils have light grayish-brown more or less shaly or loamy surface soils underlain by yellowish-brown or yellowish-gray clay loams. Parent grayish and yellowish shales and sandstones occur at moderate depths. Other important soils in the area are: (1) Poorly drained Croton soils with heavy, mottled claypan subsoils; (2) strongly developed, deep and productive Bucks soils, derived from Indian-red sandstones and shales; (3) more or less stony Mont-

alto soils, derived from diabase trap rocks; (4) dark-gray and moderately productive Lehigh soils developed from blue-gray slate; (5) some very productive Hagerstown and Duffield soils; and (6) imperfectly and well-drained bottom soils, and many others of minor importance. Practically all soils are moderately to strongly acid in reaction except where limed.

Use.—Land use is well adjusted to soils and farmers are prosperous. Dairying and general farming are most important, and the principal crops are hay, wheat, corn, oats, pasture grasses, and some potatoes, vegetables, and fruits. Excellent markets are within easy reach of most of the farms of the area.

Moderate sheet and gully erosion affect the sloping areas, and steeper slopes are sodded or kept in woods.

Rayne-Gilpin Area

Geographic setting.—The Rayne-Gilpin soil area embraces parts of the very rolling and hilly Allegheny Mountains and Kanawha sections of the Appalachian Plateau in west-central Pennsylvania. The land is a strongly and maturely dissected plateau with elevations ranging from 1,200 to 1,500 feet above sea level. More gently sloping ridge tops and valley lands and many steep hillsides are cleared and either cultivated or in pasture, and the remainder of the land is covered by second-growth timber. Valleys are narrow but there are flood plains and small terraces along larger streams.

Climate.—Cool-temperate and humid with 40 to 50 inches of precipitation, a little more than half falling between April and September, inclusive. Winters cold and summers mild. Frost-free season 130–150 days.

Native vegetation.—Oak, hickory, poplar, maple, walnut, dogwood, and other deciduous forest trees. Undergrowth of laurel, huckleberry, ground pine, and many other shrubs.

Parent materials.—Gray, yellowish and buff-colored acid sandstones and shales of Pennsylvanian age.

Soils.—Virgin Rayne soils are typical members of the Gray-Brown Podzolic group. They have a thin leaf litter underlain by (1) a thin black leafmold, (2) 1 or 2 inches of grayish-brown silty or loamy soil, (3) about 8 inches of pale yellowish-brown silty or loamy soil, (4) about 20 inches of buff or yellowish-brown compact silty clay loam, and (5) about 30 inches of disintegrated and weathered sandstones and shales. Flaggy pieces of sandstone and shale are common throughout the profile. Gilpin soils have somewhat similar horizons but are less strongly developed. The true soil is seldom more than a foot thick and there are many rock outcrops. Imperfectly drained Cookport and Cavode soils occupy gently sloping uplands and have claypan or hardpan subsoils. Poorly drained Atkins soils and well drained Pope soils occupy first bottoms along streams, and imperfectly drained Monongahela soils are on river terraces.

Use.—General farming in support of dairying is characteristic. Corn, oats, wheat, rye, buckwheat, hay, and pasture grasses are principal crops and farmers are moderately prosperous. Soils need fertilizing and soil conservation is becoming an increasingly important problem because of erosion.

Sassafras-Collington Area

Geographic setting.—This soil area extends from near Norfolk north across the eastern part of Virginia, Maryland, Delaware, New Jersey, and extreme southeastern Pennsylvania. In Virginia and Maryland it is known as the Chesapeake Bay region. It is characterized by broad, almost level or undulating areas with some gently rolling, hilly, and broken sections where the uplands break off to the lower lying terraces and streams. Most of it lies favorably for farming operations and the use of light tools and heavy machinery. It ranges in elevation from near sea level to 200 or more feet above. There are numerous wide, deep tidal streams along the coast. Most of the area is well drained and only the flatter areas and slight depressions require artificial drainage. Drainage is favored by the sandy and gravelly substratum underlying most of these soils at 3 to 5 feet.

Climate.—Oceanic; winters mild to moderately cold; summer heat tempered by ocean breezes. Considerable climatic range in the area. At Eastville, Va., mean annual temperature is 59° F., rainfall 40 inches, frost-free season 220 days. At Vineland, N. J., mean temperature is 53°, rainfall 46 inches, and frost-free season 185 days.

Native vegetation.—Heavy forests of white, black, red, and post oaks, walnut, and black locust; reforested areas largely Virginia pine (*Pinus virginianus*).

Parent materials.—Soils are developed from unconsolidated beds of sands, sandy clays, and clays and from greensand or glauconitic material.

Soils.—Soils are characterized by their brown color, sandy texture (ranging from coarse sand to silt loam), mellow, friable consistency and easy tillage, and medium to strongly acid reaction. Sassafras soils, which predominate, have brown surface soils and yellowish-brown to reddish-brown friable sandy clay or sand subsoils. Collington soils differ from the Sassafras in having a slightly greenish cast, being derived from greensand or glauconitic material, and containing more phosphorus and potash. On low flat land and in slight depressions are areas of Elkton soils, poorly drained, strongly acid, with gray surface soils and gray, heavy, sticky, sandy clay or sticky clay subsoils, mottled with yellow or rust brown. Keyport soils are intermediate in color and drainage conditions between the Sassafras and Elkton. Shrewsbury and Keansburg soils differ from the Sassafras in their poorer drainage, heaviness of subsoils, and mottled coloration, whereas the Colts Neck soils are reddish-brown in the surface, red in the subsoil, and rest on a nearly pure greensand marl. Leonardtown soils have grayish-yellow surface soils, yellow subsoils, and a well-defined hardpan layer. They occur on high flat upland areas where there has been practically no erosion. There are also small areas of muck, extensive areas of tidal marsh, and narrow bands of coastal beach.

Use.—This is the main market-gardening area along the Atlantic seaboard. Potatoes and sweetpotatoes are grown in large quantities on the Eastern Shore of Virginia and Maryland and in New Jersey, and tomatoes, asparagus, cabbage, peppers, beans, eggplants, onions, peas, sweet corn, watermelons, and cantaloups are grown for market in the large cities. The canning of peas, tomatoes, snap beans, and sweet corn is an important industry in the Chesapeake Bay region and in New Jersey. Some tobacco is grown for export trade. Main staple crops are wheat, corn, oats, and hay crops, including alfalfa. Some of the highest yields of wheat over a long period of time in the eastern United States have been produced on the heavier members of the Sassafras soils in Kent County, Md. Dairying is of importance throughout the area, particularly near the large markets. The soils used for the production of truck crops, potatoes, sweetpotatoes, and tobacco are heavily fertilized. The soils over considerable areas are used to excellent advantage. The houses, barns, and general surroundings indicate prosperity of the farmers.

Spencer Areas

Geographic setting.—The Spencer area of central Wisconsin and the small area to the northwest in Barron County consist in general of a series of long, gentle swells and smooth flats. Well-kept farms with the inevitable silo, large basement barn, pasture, and wood lot characterize particularly the southern portion and Barron County. No sharply defined valleys exist, although small streams are numerous. The continuity of the major area is broken by a northeast-southwest ridge of morainic hills crossing Taylor County. The general elevation ranges from about 1,000 to 1,400 feet above sea level.

Climate.—The climate is continental with the extremes of winter more marked than those of summer. Average annual rainfall is about 32 inches, of which approximately one-half comes in May, June, and July. The growing season averages about 120–130 days in the south and 100–110 days in the north.

Native vegetation.—The original forest consisted of hardwoods, pine, and some hemlock. Present growth is chiefly maple, yellow birch, basswood, elm, ash, and aspen.

Parent materials.—Most of the area lies within the older glacial drift region of pre-Wisconsin age. The northern part has been overridden but only slightly affected by the late Wisconsin drift. Loessial deposits may have contributed slightly to the surface material. The underlying rock is principally granite.

Soils.—The Spencer soils [2] are easily predominant. The Spencer silt loam with its rolling phase is by far the most important type. The surface 8 to 10 inches is a dark brownish-gray, very smooth silt loam which dries to an ashy gray. The subsoil is yellow and mottled yellow and gray, which grades at about

[2] Spencer soils have been called Colby by the Wisconsin Geological and Natural History Survey (*460*).[3]
[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

15 inches into a compact, tenacious, and impervious clay loam highly mottled with yellow, gray, rusty brown, red, and blue. At 3 to 4 feet the light-brown, relatively impervious, gritty and sandy clay loam of the acid parent drift is usually encountered. The outstanding characteristics of the Spencer silt loam are: (1) The mottled and impervious nature of the subsoil, (2) its acidity, (3) the high silt content, (4) the gentle relief and imperfect drainage.

In poorly drained depressions and along stream courses occur members of the Whitman series, the chief characteristics of which are: (1) Poor drainage, (2) accumulation of organic matter in the surface, and (3) the presence of stone.

Along the southern border, Vesper silt loam occurs where the underlying rock is sandstone.

Use.—This is an important dairy section and has developed in part as a result of the climatic and soil conditions, which favor pasture grasses, hay, small grains, and silage corn. Peas are an important special crop. Practically all the land is potentially tillable.

The principal problems have been the provision of adequate drainage, tillage of a heavy soil, and the need for lime. Phosphorus is an essential supplement to farm manure. The shorter growing season and more numerous stony areas, as well as the greater distance to market, are responsible in part for a less dense farm population in the northern part.

Figure 10.—Wheat on Willamette loam.

Willamette-Amity-Dayton Areas

Geographic setting.—The Willamette, Amity, Dayton, and associated soils occur in the Willamette Valley in western Oregon with outlying areas in southwestern Oregon and Washington. They are associated with the red-hill soils of the Aiken, Sites, Olympic, and Melbourne series, and with the alluvial Chehalis and Newberg soils of the stream bottoms. They occupy areas of smooth to slightly undulating relief, 200 to 600 feet above sea level. Drainage ranges from good to very poor. The country is well populated, with old and stable rural communities, numerous towns, and farms of small to moderate size.

Climate.—Humid, with mean annual rainfall of about 40 inches, most of which occurs during the fall, winter, and spring months. Mild winters with little or no snow, and a growing season of about 175 to 200 days.

Native vegetation.—Tall grasses, mainly destroyed by cultivation, with fir, scrub oak, and maple, the wooded areas probably of later encroachment. Sedges and grasses in wet meadows.

Parent materials.—Alluvial valley-filling materials derived mainly from basaltic and sedimentary rocks.

Soils.—These soils are mildly to moderately acid and have moderate to low content of organic matter. Surface soils are mostly loams and clay loams, ranging in color from rich brown through grayish brown to light gray or nearly white. The well-drained Willamette soils have friable brown surface soils over mellow, permeable lighter brown subsoils; Amity soils—of slower drainage—have grayish-brown surface soils and lighter colored subsoils with rusty iron stains; Dayton soils are poorly drained Meadow Podzols, with a very thin gray or dark-gray surface layer (A_1) over a light-gray or white ashy subsurface (A_2) layer, heavy tough dark-gray or dark olive-gray clay subsoil, and substratum of lighter olive-gray material of somewhat lighter texture. There are small rusty-brown iron pellets or concretions in both surface soil and subsoil.

Use.—The Willamette and Amity soils are the most important agricultural soils of the area (fig. 10). They are used for dairying, general farming, prunes, walnuts, berries and other fruit, and special crops. Dayton soils are acid, unproductive, and in need of drainage. Hops, berries, and truck crops are important on the slightly lower lying alluvial Chehalis and Newberg soils of the stream bottoms.

Wooster-Mahoning Areas

Geographic setting.—The Wooster-Mahoning soil areas lie chiefly within the Kanawha section of the Appalachian Plateau in northeastern Ohio, northwestern Pennsylvania, and western New York, and overlap the central lowlands in central Ohio (*108*). The country is a mildly dissected, undulating to rolling peneplain with occasional steep slopes at the edges of river valleys. Smooth slopes are occasionally broken by hummocky glacial moraines and by relatively flat alluvial terraces and flood plains. Much of the land is cleared and in pasture or cultivated crops. Frame houses and barns are more common than brick and stone buildings, but they are usually well-built and comfortable.

Climate.—Moist and temperate; 35–40 inches of well-distributed precipitation; 140 to 170 days of frost-free weather (greater part of area, 140–150 days). Cold winters; warm to hot summers.

Native vegetation.—Largely deciduous forests, varying greatly in composition according to soils and drainage conditions.

Parent materials.—Largely glacial drift composed of weathered acid sandstones and shales; a little limestone mixed with some of the drift. Some silty and clayey more or less calcareous glacial materials.

Soils.—Wooster soils have brown or yellowish-brown, friable, loamy, acid surface soils over yellowish-brown friable clay loam subsoils over deep glacial till composed of weathered acid sandstones and shales. Drainage is good throughout. They occur on deep valley till and on upland till plains with gentle slopes. Mahoning soils are grayish, imperfectly drained, heavy in texture, and are developed on very clayey more or less calcareous compact drift with very few stone fragments. They are acid above and calcareous below about 30 or 40 inches. They are common on till plains in the northern part of the area and are difficult to distinguish from heavy members of the Caneadea series developed on lake deposits. There are large areas of imperfectly and poorly drained upland soils which have hardpan or claypan subsoils. Some are slightly calcareous in lower horizons. Chenango soils are common on terraces and there are many kinds of bottom soils in the valleys.

The area east of Lake Ontario has little or no Wooster or Mahoning soils but is covered dominantly by the moderately productive soils of the Worth series with grayish-brown friable sand, gravelly and loamy surface soils, brown or pinkish-brown slightly heavier upper subsoils, and compact gray and reddish sandstone and shale glacial till substrate. Ontario, Dunkirk, Chenango, and other soils are of less importance.

Use.—Hay, pasture, and general farm crops in support of dairying. Some fruits and vegetables near cities. Wooster, Chenango, and some of the bottom soils are among the most productive. Yields on hardpan and claypan types depend on thickness of friable upper horizons and on artificial drainage. Mahoning and Trumbull soils are only moderately productive when drained.

Erosion is serious only on steeper cultivated slopes. Most soils need lime, organic manures, and complete fertilizers.

Westmoreland Areas

Geographic setting.—The Westmoreland areas are located near the western edge of the Appalachian Plateau in western Pennsylvania, northwestern West Virginia, and east-central Ohio. The plateau is severely dissected, the country being broken by narrow ridges and V-shaped valleys. The hillsides are marked by successive short benches which give the landscape the peculiar appearance of steps. Elevations range from 500 to 800 feet above sea level along stream bottoms to 1,200 to 1,500 feet along the ridge tops. The associated soils of the Rayne-Gilpin area on the north and east and the Upshur-Muskingum area on the west and south are in places intermingled with the soils of this area.

Climate.—The winters are moderately cold, the summers hot, and the two seasons are of about equal length. The rainfall ranges from 38 to 46 inches from west to east.

Native vegetation.—Hardwood, dominantly oak. Present forest consists of wood lots.

Parent materials.—Alternate thin beds of limestone, calcareous and acid gray shales, and sandstone.

Soils.—Westmoreland soils are dominant. They have brown to grayish-brown mellow surface soils over yellow-brown friable subsoils grading below 20 inches into yellow friable lower subsoils or olive-yellow heavy blocky clay, according to the parent material. These soils are rarely deeper than 3 feet to bedrock. Brooke soils, occupying smaller areas, are developed from limestone, have heavy granular soils over olive-yellow blocky clay subsoils. Belmont soils developed from red shales and limestone are reddish-brown heavy soils over Indian-red clay subsoils. Gilpin and Muskingum soils are described in connection with other areas. Elk, Captina, and Robertsville soils are developed upon the terraces, and Huntington, Lindside, and Melvin soils occupy the comparatively narrow bottom lands.

Use.—Most of this land is cleared and a large area is used for pasture, dominantly bluegrass. Corn, wheat, oats, buckwheat, and potatoes are grown upon small fields. Yields are moderate. Bottom lands are used mainly for corn. Apple orchards are developed in places. Cattle raising is the leading farm activity, and where markets permit, dairying is practiced.

Westmoreland soils are naturally among the most fertile soils of the Allegheny Plateau region. They support good bluegrass sod. Overgrazing and cultivation of the steep slopes have resulted in severe erosion in places and nearly all of the land has suffered in some degree from erosion. Improved pasture practices and strip cropping are essential to maintenance of successful agriculture upon this land.

PRAIRIE SOILS

The typical Prairie soils have developed in cool, moderately humid climates under the influence of a grass vegetation. These soils occur in the Middle West and occupy a large part of the Corn Belt. The profiles are characterized by dark-brown to nearly black, mildly acid surface soils underlain by brown well-oxidized subsoils. The parent materials have a wide range in composition especially in their content of lime. The Prairie soils differ from those of the Chernozem group in having a slightly lighter color of the surface soil and in the absence of a zone of lime accumulated by soil-forming processes. This group includes soils which rank among the best in the United States in the production of corn and oats. Other small grains and hay and forage crops are grown.

Included in the Prairie soil group are somewhat untypical areas in California, and in northern Idaho, northeastern Oregon, and southeastern Washington. The Altamont-Los Osos-Cayucos areas in California are developed under a warmer climate than the typical Prairie soils, with moist winters and dry summers. The soils are somewhat lighter in color and there is little growth of vegetation in summer unless the land is irrigated. The Nez Perce areas in the Northwest also have drier summers than do the typical Prairie soil areas of the Middle West.

Altamont-Los Osos-Cayucos Areas

Geographic setting.—The Altamont, Los Osos, Cayucos, and similar and associated soils are in the coastal hill and mountain region of California, with scattered and less typical areas marginal to the interior valley (fig. 11). Elevations range from sea level to 4,000 feet with the larger part between 500 and 2,500 feet.

They occupy rounded ridges and smooth but frequently steep slopes with rather infrequent outcrops of parent rocks and with occasional gullies and local landslip scars and hummocks. They are frequently closely associated with the Diablo soils.

Climate.—Mediterranean type of climate, with rainfall of 12 to 25 inches. Warm, dry summers, mild, moist to wet winters and frequent fogs.

Native vegetation.—Characteristically open parklike grass, brush, and woodland association. The southern and western exposures usually grass-covered with occasional oaks. The more sheltered northern and eastern slopes frequently covered with brush, California buckeye, madroña, and live oaks.

Parent materials.—Sedimentary rocks often strongly metamorphosed and of both siliceous and calcareous character.

Soils.—The Altamont and Los Osos surface soils are brown to dark brown; the Cayucos, darker, dull brownish gray to black. They are dominantly of loam to clay texture, often of adobe structure, and neutral to slightly acid in reaction. The subsoils are lighter brown to yellowish-brown, moderately illuviated and of blocky structure, and in the Altamont soils mildly to moderately alkaline in reaction and with lime in the deeper subsoils and parent materials.

FIGURE 11. Characteristic round-topped hills of the Altamont soils in the semiarid coastal hill section of California. These soils are used for the production of small grains, hay, and pasture.

Bedrock usually occurs at a depth of about 30 to 40 inches. The Altamont soils are developed on irregularly calcareous materials and under comparatively low rainfall; the Los Osos and Cayucos are more frequently confined to the immediate coastal areas of higher rainfall and more frequent fogs which arrest loss of moisture through transpiration and evaporation during the rainless summer periods.

Use.—The land is without water supply for irrigation, and is used largely for production of grain, hay, and pasture in connection with dairying and stock raising. The grain—wheat and barley—is cut green and cured for hay in the drier years. Table corn, beans, and peas are important crops near the cities and where rainfall is sufficient to mature the crops. Measures for protection from sheet erosion and gullying are essential on cultivated or heavily grazed land if present land use is to be maintained.

Carrington-Clyde Areas

Geographic setting.—These areas include important soils of the glaciated part of the northern prairies. The most uniform and representative area is in northeastern Iowa. Other areas are in Illinois, Nebraska, Kansas, Minnesota, and

Wisconsin. The Carrington soils are on undulating to gently rolling uplands. The intervening flat areas of Clyde soils are in narrow depressions and shallow valleys, where drainage was formerly deficient. The Carrington soils are in the heart of the Corn Belt and rank among its most productive soils. The landscape in general is characterized by pleasing contours and well-improved farms. Elevations range from 600 to 1,200 feet above sea level.

Climate.—Average annual precipitation across the region from west to east is 30 to 35 inches. Mean annual temperature range from north to south is 45° to 50° F. Crop losses from drought or early frosts rarely occur.

Native vegetation.—Tall grasses with bluestem and bunch grass predominating. Scattered hardwood trees along ravines and stream bottoms.

Parent materials.—Glacial drifts of the older stages which have been leached to a depth of several feet. Clyde soils are developed from drift in part reworked by streams, under conditions of poor drainage.

Soils.—The soils of this region belong mainly to two series, the Carrington and the Clyde. A number of associated soils on flood plain and terraces cover a small part of the area. The loam type is representative of the Carrington series. Its surface soil is dark grayish-brown friable loam to an average depth of 11 inches. Below this is a brown or yellowish-brown loam of similar texture, well-oxidized and leached of lime. The underlying parent material is yellowish-brown glacial drift, which is free of lime to a depth of 6 feet. Glacial boulders are scattered over the surface and through the soil. The other Carrington types differ from the loam mainly in the texture of the surface soil. The Clyde soils have black surface layers and gray or mottled gray-and-yellow subsoils. The northern extension of the Carrington-Clyde area along the Mississippi River in central-eastern Minnesota is composed largely of dark-colored soils, much sandier than the typical soils of these series.

Use.—From 60 to 90 percent of the land in the Carrington areas is used for cultivated crops. The remainder is in hay and pasture. Corn is the most important crop, but oats has only a slightly smaller acreage. Since this region is one of dairying and meat production, nearly all crops grown are fed to animals on the farms. The greater part of the Clyde areas is used for pastures and feed lots. Where drainage is adequate these soils produce large yields of corn. The sandy soils near Minneapolis and St. Paul are extensively used for market gardening.

Clarion-Webster Areas

Geographic setting.—Clarion, Webster, and associated soils are developed in three principal areas, one in north-central Iowa and south-central Minnesota, the other two in eastern Illinois and western Indiana. These areas are noted for their production of corn. The soils lie on undulating to gently rolling till-covered plains on which the Clarion soils occupy the higher land and the heavier and blacker Webster soils the more nearly level tracts. In Iowa both soils occupy about equal areas interlaced in an intricate pattern. Northward in Minnesota, the Webster areas decrease as the basins become deeper and are occupied by lakes. Elevations range from 1,000 to 1,250 feet above sea level.

Climate.—Average precipitation ranges from 25 to 32 inches, which is sufficient for the crops grown; the number of frost-free days ranges from 140 to 160. The season is often too short for corn in the northern part.

Native vegetation.—Rank bunch grasses on the higher land and marsh grasses and sedges on poorly drained areas.

Parent materials.—Calcareous glacial drift of the late Wisconsin stage. The Clarion soils are well drained, whereas the Webster soils have developed under conditions of poor drainage.

Soils.—Clarion soils have very dark grayish-brown surface layers underlain by brown material. Below 30 inches the unleached calcareous glacial drift is encountered. Webster soils have black surface layers with gray or mottled gray, yellow, and brown calcareous subsoils.

Use.—Nearly all the land is cultivated. These areas are not surpassed by any other of equal size in the production of corn. Over a large part of them the average acre yield ranges from 32 to 45 bushels, but yields of 100 bushels are not uncommon. Oats ranks next in importance. These crops are mostly sold for cash. Crops of minor importance are barley, clover, timothy, sorghum, soybeans, flax, and pasture grasses.

Clarion soils in Illinois have declined in productivity very rapidly in recent years. Applications of fertilizers and the incorporation of organic matter are required to maintain their fertility.

Florence-Newtonia Area

Geographic setting.—In eastern Kansas and Oklahoma an area of rugged stony hills, known as the Flint Hills, presents distinctive features of soil, landscape, and agriculture. The existence of the hills is due to the presence of large amounts of chert (commonly called flint) in some of the outcropping limestone beds. The chert is more resistant to erosion than the limestone and shale so that as the softer rocks are destroyed hills remain capped by chert and bordered by steep slopes covered with chert fragments. In places the chert stands up as ledges enclosing narrow, comparatively smooth areas. Elevations range from 1,200 to 1,500 feet above sea level.

Climate.—Average annual precipitation ranges from 31 to 35 inches in different parts of the area. Mean annual temperature is 55° to 60°F. More than half the rain falls during the growing season.

Native vegetation.—The predominant grass is big bluestem. Little bluestem is also common.

Parent materials.—Several interbedded cherty limestones and shales.

Soils.—A number of soils have developed over the various kinds of limestone and shale. These have not been studied in detail. In general they are thin, with many exposures of limestone. The Florence, Crawford, Newtonia, and Summit series are represented among the soil types. The surface soils are dark-colored and usually acid. At a depth of a few inches they become brown or reddish brown and gradually more calcareous until limestone is reached. Chert fragments are scattered over the surface and through the soil mass.

Use.—The area is well-suited to the production of bluestem grasses and is largely used for this purpose. The mass of stone fragments in the soil discourages cultivation but does not prevent the penetration of grass roots into the highly productive soil. Stockmen claim that this area is not excelled for grazing by any other nonarable land in the country. The comparatively small level areas are suited to the production of corn, sorghums, alfalfa, sweetclover, and fruit.

Nez Perce Areas

Geographic setting.—The Nez Perce, Alicel, Waha, and associated soils occupy rolling, mostly treeless, uplands in the Columbia Plateau wheat section of Washington, Oregon, and Idaho, at elevations of 2,000 to 4,000 feet. They lie nearer the mountains and at higher altitudes than the Ritzville, Walla Walla, and Palouse belts, although some of the higher lying Palouse soils are included. The section is rather thinly populated.

Climate.—Subhumid. Rainfall 20 to 30 inches. Summers dry with moderate temperatures. Winters rather long and cold.

Native vegetation.—Largely grass and perennial herbs. Scattered yellow pine in places.

Parent materials.—Largely loess (floury wind-borne material); in places, disintegrated basalt (lava).

Soils.—Surface soils are dark grayish-brown or black, mellow, granular silt loams or silty clay loams. Some small areas of sandy loams are included. Upper subsoils are rusty or yellowish-brown compact silty clay loams and clays. Lower subsoils are light brown or grayish brown, rather heavy, but less compact than the layer above. In most places lime carbonate is not present within 6 feet of the surface. Some included areas are rather steep, shallow, and stony, and areas under cultivation are in places subject to rather serious accelerated erosion.

Use.—Mostly cultivated (dry-farmed). Wheat is by far the most important crop and yields heavily. Minor crops are alfalfa, timothy, clover, peas, beans, corn, potatoes, and tree fruits, all of which give moderate or low yields because of lack of moisture in summer. Irrigation on small areas has resulted in large increases in yields. Application of lime increases production of alfalfa.

Crop rotation should be practiced, with occasional use of sod. Contour plowing is desirable on more sloping areas to minimize run-off and erosion, and strip cropping may be desirable in places.

Summit-Bates Areas

Geographic setting.—Summit-Bates and similar and associated soils occupy areas lying mainly in eastern Kansas but extending into northern Oklahoma and western Missouri. The country ranges from nearly level to rolling, most of it being undulating or gently rolling. The upland was originally treeless, but trees grew along the stream valleys. The landscape has been changed by the planting of trees around farmsteads and in wood lots. Elevations range from 600 to 1,000 feet above sea level.

Climate.—Average annual rainfall, 30 to 40 inches, well distributed through the growing season. Mean annual temperature 50° to 56° F. Average length of frost-free season ranges from 170 to 180 days in different localities. Winters are mild or moderate; summers are hot.

Native vegetation.—Tall grasses—bunch grass and bluestem predominating.

Parent materials.—Summit soils are developed from calcareous shales, fine-grained sandstones, and limestones; Crawford and Newtonia, from limestones and calcareous shales; Oswego and Gerald from shales or shales interbedded with limestone; and Bates, from noncalcareous sandy shales and sandstones.

Soils.—Summit soils have dark brown to black granular surface soils with acid reaction, over dark-brown subsoils somewhat heavier in texture but of crumbly consistency. Organic matter decreases gradually from the surface downward. At an average depth of 3 feet is a substratum of brown clay. Crawford and New-

FIGURE 12.—Characteristic topography of Summit silt loam, Caldwell County, Mo.

tonia soils have dark-brown or dark reddish-brown topsoils over reddish-brown or red clay subsoils. The Crawford soils are more deeply developed than the Newtonia. The latter are thin, in places are red at or near the surface, and have a high content of chert fragments. Bates soils have dark-brown surface soils with brown subsoils and are underlain by partly decomposed sandstone. Associated soils of the alluvial bottom lands are those of the Verdigris and Osage series.

Use.—General farming, with corn, oats, and forage crops, is commonly practiced in this area. Sorghums, millet, and soybeans are grown to a small extent. A large acreage is in pasture (fig. 12). All conditions make this area well adapted to livestock raising and dairying. Many beef cattle are raised, grazed, and fed. Fruit growing is an important enterprise in many places. On Crawford soils, apples are grown in places on a commercial scale. Cherries, grapes, and berries are widely grown. The soils generally are quite productive and sustain a prosperous agricultural population with a good standard of living. The Verdigris and Osage soils are highly productive and largely used for crops.

Tama-Marshall Areas

Geographic setting.—Large areas in Iowa, Illinois, Missouri, Nebraska, southern Wisconsin, and southeastern Minnesota are covered by mellow, dark-colored silt loams. The surface is undulating to gently rolling. Comparatively small areas may be almost level, but drainage is everywhere adequate. On only a very small part of the land does the steepness of the slope prevent cultivation. About

90 to 96 percent of the land is tillable. Mellow and productive soils, pleasing landscapes, and favorable climate combine to make these areas among the most desirable of the Corn Belt. Elevations range from 800 to 1,500 feet above sea level.

Climate.—The range in mean annual precipitation is from 30 to 35 inches. The average number of days without killing frost ranges from 150 to 170.

Native vegetation.—Tall grasses, chiefly bluestem. Trees occupy narrow strips along the stream bottoms.

Parent materials.—Loess of Peorian age. In smooth areas in the western part, this material is leached of lime carbonate to a depth of 30 inches, and toward the east to greater depths.

Soils.—In Illinois, Minnesota, and eastern Iowa, the Tama soils are dominant. Near the Missouri River, especially in northwestern Iowa, the Marshall soils occupy almost all of the uplands. The Marshall surface soils are dark grayish brown and the subsoils are light brown to yellowish brown. Both soil and subsoil are loose and friable. The substratum of parent loess is pale yellowish brown or grayish yellow silty material high in lime. The Tama soils have a similar profile except that the lime has been leached from the parent material to a depth of many feet. With these soils are associated a number of soils of minor importance in area and of lower productivity. These include several dark-colored soils of stream bottoms and terraces and a few light-colored soils on the steeper and more severely eroded slopes.

Use.—These soils are in the heart of the Corn Belt and, all facts considered, they are not excelled for corn production by any other soils of the United States. Corn is the principal crop, and it is grown as often as it is possible to do so without injuring the soil. Oats ranks second in acreage. Clover and timothy hay, barley, and soybeans are minor crops. Alfalfa and sweetclover are grown on the Marshall areas to a small extent. These soils erode rapidly under cultivation and means should be taken for their protection.

REDDISH PRAIRIE SOILS

The Reddish Prairie soils lie south of the region of the true Prairie soils. They have a redder color, probably due partly to the reddish color of the parent materials and partly to the warmer climate under which they have developed. These are for the most part productive soils, and much of the land is cultivated. The Zaneis-Renfrow areas are the only representative areas of these soils.

Zaneis-Renfrow Areas

Geographic setting.—The Zaneis, Renfrow, and associated soils occupy a discontinuous belt of undulating to rolling prairie country extending from south-central Kansas through Oklahoma into north-central Texas, and lying at the extreme western edge of the pedalferic soil region. Elevations range from 500 to 1,000 feet above sea level. This is a fairly prosperous farming country.

Climate.—Warm-temperate and rather dry. Average annual rainfall ranges from 28 to 35 inches. Summers, hot and sometimes droughty; winters short and mild.

Native vegetation.—Chiefly tall prairie grasses with some grama grass.

Parent materials.—"Red Beds" formation—beds of red calcareous clay or sandy clay, containing in places strata of gypsum, limestone, and sandstone.

Soils.—On smooth land, soils are deep and have red or brown surface soils, largely of silt loam or very fine sandy loam texture, over red and brown crumbly clay or sandy clay subsoils. Zaneis and Kirkland soils are the more important of these deeper soils. Rather large areas of sloping lands have thin red soils, which belong largely to the Renfrow and Vernon series. There are small associated areas of sandy Derby and Pratt soils.

Use.—The soils, except where extremely sandy or very shallow, are fairly productive. Farms range in average size from 130 to 240 acres in different counties, and the area of cropland ranges from 40 to 70 percent of the total land area. The more important crops are wheat, oats, corn, cotton, hay, and forage. Yields are good and fairly certain. The shallower soils, which are naturally susceptible to erosion damage, should be and are largely used for grazing.

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RED AND YELLOW PODZOLIC SOILS (LATERITIC MATERIALS)

The Red and Yellow Podzolic soils occur throughout an extensive region in the southeastern part of the United States, including most of the Coastal Plain, much of the Piedmont, the Ozark plateaus, and the southern ends of the Appalachian Plateau and limestone valleys. Relief varies from flat to rough and hilly, and elevations from sea level to 2,000 feet. The climate is warm-temperate to subtropical, and humid. Native vegetation was largely forest—pines dominating in the Coastal Plain and oaks and other hardwoods in the Piedmont and Appalachian Plateau.

The soils are strongly leached, acid in reaction, and low in organic matter and mineral plant nutrients; the surface soils are prevailingly light-colored and sandy, and subsoils are heavier, tougher, and of red, yellow, or mottled color. Though low in inherent fertility these soils are easily tilled and respond readily to fertilization. They are important producers of cotton, corn, tobacco, citrus fruits, peaches, pecans, vegetables, peanuts, sweetpotatoes, soybeans, cowpeas, and a wide variety of other crops.

Large areas of red soils exist in the lower mountains and foothills of northern California and western Oregon. These are included in the Aiken-Konokti-Sites areas. They are largely forested, though some of the lower, smoother lands are cultivated.

Aiken-Konokti-Sites Areas

Geographic setting.—The Aiken, Konokti, Sites, and similar and associated soils occupy extensive belts in western Oregon and northern California, extending southward along the western slope and foothills of the Sierra Nevada, where they are associated with the Holland and Sierra soils. Elevations range from 500 to 4,000 feet above sea level. The lower and smoother areas are intensively cultivated and occupied by thrifty communities and farm homes. The more elevated areas of adverse topography and climatic conditions are sparsely populated and merge with the Olympic and lighter colored podzolic soils. The soils occupy foothills and mountain slopes of smooth to broken surface and gentle to abrupt slope, frequently deeply cut by scenic stream canyons and narrow valleys.

Climate.—Mean annual rainfall ranges from 25 to 50 inches. Summers long, warm, and dry; winters wet, with considerable snow in the more elevated areas, which are subject to early fall and late spring frosts. Killing frosts infrequent in the lower areas having good air drainage.

Native vegetation.—Open ponderosa pine, with some digger pine, live oak, and shrubs in southern and less elevated marginal areas in California; ponderosa pine, incense cedar, and fir at higher altitudes and in more northern areas of higher rainfall.

Parent materials.—Basaltic and andesitic bedrocks, diabase, and basic volcanic tuffs and breccias and associated shales and sandstones.

Soils.—Dominantly loams to clay loams, somewhat lateritic. Surface soils of red or dull-red color under a thin layer of forest litter. Subsoils a more pronounced red, compact, of heavier texture, nutlike or blocky in structure, and of high colloidal content. Soil and subsoil are mildly acid in reaction and contain small, rounded, shotlike aggregates or concretions cemented by sesquioxides of iron and manganese and with accumulated phosphorus in insoluble and unavailable form. Soils in areas of lower rainfall are frequently shallow and broken by outcrops of bedrock.

Use.—These areas include some of the most valued soils for highly specialized production of deciduous tree fruits, especially pears, apples, prunes, plums, and walnuts. Some of the cultivated slopes are steep, and tillage operations require experience and care. The lay of the land, except in the smoother, less elevated areas, is unfavorable for general farming, and forested and cut-over areas form an important and extensive resource for forestry and recreational uses if wisely managed.

Baxter-Lebanon Areas

Geographic setting.—The Baxter, Lebanon, and associated soils lie in Missouri, Arkansas, and Oklahoma, mostly in the southwestern part of the Ozark

Mountains. The areas include the better farming land on the border of the uplift. The surface in general is gently to sharply rolling with large areas of rough valley land with intervening relatively smooth divides. The elevation ranges from 900 to 1,300 feet above sea level and surface drainage is everywhere good. The region is noted for self-subsisting farmers producing on small farms a wide variety of field and orchard crops.

Climate.—Average annual precipitation, 40 to 45 inches, well distributed through the growing season. Mean annual temperature 54° to 58° F. Frost-free season 170 to 180 days.

Native vegetation.—Hardwood forests, mainly of blackjack and post oak on the flat and gravelly areas, and various oaks, hickory, maple, elm, and walnut on the better land.

Parent materials.—Cherty limestones and magnesian limestones. Occasional beds of sandstones or shales locally modify the soil.

Soils.—Baxter soils are most important in the agriculture of this region. The surface soils are light grayish brown or grayish yellow with a thin upper layer of darker color. The subsoils are reddish brown and somewhat heavier in texture than the surface soils. Both soil and subsoil contain chert fragments. These soils cover the undulating to hilly areas. The Lebanon soils are developed on flat areas. The surface soils are similar in appearance to those of the Baxter series but they are underlain by yellowish-brown silty subsoils which grade into reddish-brown tough clay. At a depth ranging from 24 to 40 inches a so-called hardpan layer is encountered, consisting of a gray and brown compact sandy clay, filled with fragments of chert and sandstone. A number of soils of minor importance, derived from limestones and shales, are associated with the Baxter soils, and soils with heavy clay subsoils occupy flat areas near the Lebanon soils. Alluvial soils of excellent quality occur along the streams.

Use.—Less than half the land is in cultivation. The rough portion is mostly timbered and is used for woods pasture. The general farm crops are corn, wheat, and oats. Much of the cultivated area is devoted to diversified farming, in which fruit growing is combined with dairying, poultry raising, stock raising, and trucking.

Cecil-Appling Area

Geographic setting.—The Cecil-Appling soil area, locally called the red-clay hill region of the South, includes the southern Piedmont. It begins in north-central Virginia, extends across the Carolinas and Georgia, and terminates in eastern Alabama. Elevation ranges from 400 feet bordering the Coastal Plain to more than 1,000 feet at the foot of the Blue Ridge Mountains. The general slope is to the east and south. The topography varies from undulating or gently rolling to rolling, steep, and broken. The smoother areas over which the relief ranges from almost flat or undulating to gently rolling occur mainly on the broader interstream ridges, whereas the strongly rolling steep and broken relief occurs on the slopes and around the heads of streams. The entire region is thoroughly dissected by numerous streams and the natural surface drainage is good, as perennial streams and intermittent streams ramify all parts and give a comprehensive drainage system. Both sheet and gully erosion have been very active on the more sloping areas under clean cultivation. Gullies have destroyed, beyond redemption by individual owners, large areas of these once-productive soils.

Climate.—Warm-temperate, mild, equable, humid, and healthful. Considerable difference in the climate in the northern and southern parts determines the kinds of crops grown. In the vicinity of Charlottesville and Danville, Va., mean annual temperature ranges from 56° to 48° F., rainfall 40 inches, growing season about 200 days. At Opelika, Ala., mean temperature is 63°, rainfall 49 inches, growing season 245 days. Rainfall is well distributed, with driest period in fall. Climate is favorable for production of tobacco and apples in northern part, cotton in central and southern parts, and peaches throughout the area.

Native vegetation.—Northern end of region dominantly hardwood forest, including several varieties of oaks, hickory, shortleaf pine, dogwood, sourwood, and poplar. In the southern end, a mixture of longleaf pine and oaks with some hickory, walnut, sweetgum, and black gum. Second growth mainly old-field pine.

Parent materials.—Granites, gneiss, and schist underlie greater part of area; smaller areas are underlain by dark-colored basic rocks.

Soils.—Medium to strongly acid in reaction, low in organic matter, but contain much potash, particularly the subsoils. Scattered over the surface locally, fragments of quartz and occasionally outcrops of granite. Soils range in texture from coarse sandy loams to clays. Small scales of mica are common throughout the soil and subsoil.

Cecil soils predominate throughout the area. They are characterized by either gray sandy loam or red clay loam surface soils, underlain by red, stiff but brittle clay subsoils. Usually at 30 to 40 inches below the surface the material is lighter in color and more friable in consistence.

Durham soils are the lightest colored and lightest textured in the Piedmont—they have gray, light-gray, or grayish-yellow surface soils and yellow friable clay or heavy sandy clay subsoils. The Appling soils are intermediate in color of subsoil between the red of the Cecil and the yellow of the Durham.

Associated with these soils are areas of Madison and Louisa soils, closely resembling the Cecil in color but differing from them in having more friable subsoils and containing a marked amount of small mica scales—the Louisa soils contain a higher content of mica and have a slick greasy feel in both soil and subsoil.

There are several large and many small areas of soils derived from dark-colored basic rocks. These soils range from red to grayish brown in the surface portion and from dark red or maroon heavy smooth clays to brownish-yellow heavy plastic clay in the subsoils. They are the Davidson, Mecklenburg, and Iredell. They are lower in potash but higher in lime than the above-described soils.

Use.—A diversified agriculture is practiced throughout this area and a good to high standard of living is maintained. In the northern part, tobacco is the main cash crop and wheat, corn, hay (timothy and clover or timothy and orchard grass), alfalfa, oats, soybeans, cowpeas, potatoes, and garden vegetables are the main subsistence crops. Apples are grown on a commercial scale in the vicinity of Charlottesville, Va. In the southern part, cotton is the dominant cash crop, but the subsistence crops are similar to those in the northern part of the area with the addition of sweetpotatoes, peanuts, watermelons, grapes, and truck crops. A few beef cattle, hogs, sheep, and horses are raised, many of the better farmers have some milk cows, and there are a few dairies near the larger cities. A large percentage of the land is under cultivation and the farms range in size from 50 to 300 acres. They are operated largely by the owners and members of the family. Soils over much of the area are used for the crops to which they are best adapted under present economic and market conditions. For example, Durham and Appling soils are peculiarly suited to the production of bright-leaf tobacco. Good markets are obtained for farm produce around the textile-, furniture-, and tobacco-manufacturing centers. Commercial fertilizers are applied to the soils used for the production of tobacco, cotton, truck crops, and locally for other crops. Soils throughout this area lend themselves to improvement and maintenance of productivity.

Caddo-Beauregard Areas

Geographic setting.—Caddo, Beauregard, and associated soils occupy the flatwoods of the Coastal Plain, relatively small areas or belts of flat or nearly flat timbered country bordering areas of Norfolk-Ruston soils on the south and east in Texas, Louisiana, and Arkansas. Surface drainage and subdrainage are slow in most places.

Climate.—Warm-temperate and humid. Rainfall averages 45 to 55 inches annually. Summers long and hot, winters short and mild. Frost-free season 250 to 265 days.

Native vegetation.—Mostly pine with some hardwoods, such as gums and oaks.

Parent materials.—Coastal Plain deposits of sandy clay and clay, probably largely of Pleistocene and Quaternary formations, and old alluvial deposits.

Soils.—The soils are somewhat similar to those of the Norfolk-Ruston areas, but on account of poor drainage the surface soils are typically somewhat lighter colored and the subsoils are mottled gray and yellow. In places the subsoils have a mottled red-gray color.

Caddo, Beauregard, Segno, Pheba, and Acadia soils are important soils of these areas. They are acid in reaction, low in content of organic matter, and rather low in inherent fertility. Where well drained, they produce well under good management and fertilization. The surface soils are largely rather sandy, but in many places they contain a fairly large amount of fine sand and silt. The subsoils are generally moderately compact to stiff sandy clays or silty clays.

Use.—A rather small proportion of the land is used for crop production, the area ranging from 5 to 20 percent in different counties covered by the soil survey. The larger proportion is cultivated in counties where alluvial soils are prominent. This lack of farming development is due to poor drainage, inadequate markets and transportation facilities, low inherent productivity of the soil, and other unfavorable conditions.

Where farmed, the land is used chiefly to produce subsistence crops for home use and cotton as a cash crop. Feed crops include corn, sorgo, and others. Farms are mostly small, the average size in different counties ranging from 40 to 70 acres. The condition of the farms and farm improvements do not indicate a high standard of living in most places. Much of the land requires better drainage—both surface

FIGURE 13.—A good crop of smoking tobacco on Clarksville silt loam in Howell County, Mo.

and subdrainage—and the soils are mostly low in organic matter and fertility, but fairly good production may be obtained by fertilization and good management.

Clarksville-Lebanon Area

Geographic setting.—This picturesque area includes the principal part of the Ozark Mountains in central and southeastern Missouri, extending into northern Arkansas. The surface as a whole is higher and more deeply cut than the adjoining prairie lands. The stream valleys are deep and narrow and are bordered by belts of rough dissected country. The higher lands are rolling, with com-

paratively narrow flat areas on the ridge tops. There is a considerable range in the character of the land, but the area as a whole presents general similarities of landscape and agriculture. Elevations range from 1,000 to 1,500 feet above sea level.

Climate.—Over different parts of the area the average annual precipitation ranges from 35 to 45 inches and the mean annual temperature from 54° to 57° F. Average number of days without killing frosts ranges from 170 to 190.

Native vegetation.—Red, white, and black oaks, hickory, and other hardwoods on rolling areas. Blackjack and post oak on flat ridges. Some shortleaf pine in southern part.

Parent materials.—Limestones and dolomites. Some are free of chert; others contain a large proportion. Granites and other igneous rocks outcrop in small areas in the eastern part.

Soils.—The principal soils on the rolling areas are stony and gravelly loams of the Clarksville series. These have gray or grayish-yellow surface soils underlain at a depth of 5 to 8 inches by heavy yellowish-brown, grayish-brown, or reddish-brown silt loams and below 24 inches by a stiff silty clay. The content of chert varies from almost nothing to 75 percent of the soil mass. The proportion of chert usually increases with depth. Lebanon silt loam occurs on the relatively smooth tables and ridge tops. The surface soil is a gray silt loam, 5 to 8 inches thick. It is underlain by grayish-yellow or grayish-brown silt loam with a slight reddish tinge. At a depth of 24 to 40 inches a compact cemented layer is encountered.

Use.—Less than 40 percent of the area has been farmed. Many areas are too rough or stony for cultivation, others have a smooth surface but are not very productive. The principal crops on the cultivated areas are corn, oats, wheat, clover, grass, and some tobacco (fig. 13). Average yields for the area as a whole are low, but small areas are very productive. The area can best be used for general farming on a small scale, and dairying and livestock production; fruit production may be profitable near markets and roads.

Dickson-Baxter Area

Geographic setting.—Dickson-Baxter and associated soils occur in Tennessee on the Highland Rim and surrounding the central basin. They extend north into Kentucky and south into northern Alabama. The surface is mostly undulating to gently rolling, with some areas almost level and others having steep slopes, ridges, and knobs. Elevation ranges from 600 to 900 or more feet. Surface drainage is good, internal drainage hindered by hardpan layer. Sheet erosion is noticeable on slopes in cultivated fields.

Climate.—Mild and temperate. In Dickson County, Tenn., the mean annual temperature is 58° F., rainfall 48 inches, frost-free season 188 days, snowfall 10 inches. Lauderdale County, Ala., mean temperature 60°, rainfall 51 inches, frost-free season 208 days. Rainfall is well distributed.

Vegetation.—Dominantly hardwoods, mainly white, red, Spanish, and post oaks, a few hickory and other trees.

Parent materials.—Impure or cherty massive limestone.

Soils.—The soils are silty in texture, have a smooth flourlike feel, contain a small amount of organic matter, and are medium to strongly acid. Dickson silt loam, the predominant type, is characterized by a hardpan layer. The surface soil is yellowish gray to light gray, subsoil brownish-yellow silty clay loam underlain at 24 to 30 inches by a dry, compact, hardpan layer of mottled gray, yellow, and brown. Baxter soils differ from the Dickson in having brown to reddish-brown surface soils, red subsoils, and no well-defined hardpan layer, although slightly compact in the subsoil. There are scattered poorly drained areas of Guthrie silt loam which has a gray soil over a mottled subsoil. Small areas of Taft soil are intermediate in characteristics between Dickson and Guthrie. Very cherty soils (Bodine) are developed on steep slopes.

Use.—Principal crops are corn, oats, timothy, redtop, cowpeas, sweetpotatoes, garden vegetables, and sorgo. Cotton is important in Alabama and southern Tennessee. A few cattle and hogs are raised for the market. These soils support a diversified subsistence type of agriculture with small farms owned and operated mainly by white people. Crop rotation is practiced and a small amount of commercial fertilizer is used.

Decatur-Dewey-Clarksville Areas

Geographic setting.—These areas contain some of the reddest soils in the limestone valleys. The largest area joins the Hagerstown-Frederick area in northeastern Tennessee, and continues southwest into Georgia and Alabama. Smaller areas lie to the west in Tennessee and northern Alabama. The surface is almost level, undulating, and gently rolling to hilly, with many parallel ridges and tablelands rising 100 to 300 feet and areas of flat land, numerous sinks, and depressions (fig. 14). The elevation ranges from about 430 to 1,400 feet above sea level. Natural drainage is good to excessive. Much of the drainage water finds its way into sinks and finally into underground passages. Erosion has been very active on sloping lands under clean cultivation, and even gullying is pronounced in many places.

Climate.—Temperate and continental. Considerable difference in temperature between the northern and southern parts of the areas. This difference is manifested in crops grown; there is no cotton in the northern portion. At Florence, Ala., mean annual temperature is 71° F., rainfall 51 inches, growing season 208 days.

FIGURE 14.—View of a representative area in the Tennessee Valley, showing Talbott stony silt loam in the foreground, Dewey and Fullerton soils in the middle distance, and Montevallo silt loam on the ridges and low hills in the background.

In the northern part of the areas temperatures are lower and the growing season is correspondingly shorter.

Native vegetation.—Most of the Decatur and Dewey soils are cleared of original hardwood growth. On ridges of Clarksville and Fullerton soils some forests remain, chiefly hardwoods—blackjack, black, Spanish, and post oaks, and some hickory, poplar, dogwood, and sweetgum—with some loblolly pine.

Parent materials.—Dewey and Decatur soils are underlain by pure limestones and dolomitic limestones; Clarksville and Fullerton soils, by dolomitic limestones and cherty limestones; associated soils, by limestone, acid shale, and calcareous shale.

Soils.—Climate and vegetation have not favored accumulation of a large amount of organic matter in the soils. Wide differences exist in the fertility of the soils, owing largely to the parent material. The soils range from medium to strongly acid in reaction. Decatur and Dewey soils are the principal red soils in the valleys. Decatur soils have red clay loam surface soils and stiff clay or silty clay subsoils, whereas the Dewey soils have brown surface soils and reddish-brown

firm friable subsoils. The Talbott soils differ from the Dewey in having heavy tough plastic clay subsoils. Colbert soils are gray in the surface portion and have yellow or reddish-yellow and mottled heavy plastic clay subsoils. Clarksville and Fullerton soils occur on the ridges. Clarksville soils have light-gray surface soils and yellow friable subsoils, whereas the Fullerton have grayish-yellow soils and reddish-yellow to light-red subsoils. There are extensive areas of Montevallo and Dandridge soils underlain by shales. They differ mainly in that the Montevallo soils are derived from acid shales whereas the Dandridge are from calcareous shales. There is also a corresponding difference in the agricultural use. There are areas of sandstone and limestone which give rise to the Christian soils and also areas of limestone and shales which give rise to the Armuchee soils. Some good agricultural soils are developed on the terraces and second bottoms. Areas of stony land are conspicuous here and there.

Use.—The main crops in Tennessee are corn, wheat, oats, rye, hay (timothy, clover, and alfalfa), Burley tobacco, sorgo, fruits, potatoes, and garden vegetables. Some or all of these crops are grown in Georgia and Alabama, and in addition a large acreage is devoted to the production of cotton, particularly in the Tennessee Valley counties of Alabama. Lespedeza is an important hay and pasture crop. Considerable dairying is carried on to supply the towns and cities with milk and butter. There are several commercial peach orchards.

The soils in some localities are handled to good advantage, having been protected from serious erosion, and are supporting a self-sufficing agriculture. The farmhouses and surroundings indicate prosperity. On the poorer soils only enough for mere existence is produced. The Decatur and Dewey soils are capable of being built up to a high state of productivity, which is fairly easily maintained.

Georgeville-Alamance Area

Geographic setting.—This area embraces the well-known Slate Belt of the southern Piedmont, extending from eastern Georgia across South Carolina and North Carolina and into southern Virginia. Surface relief ranges from undulating or gently rolling to rolling, steep, and broken. A large part lies favorably for farming. Most of the area is naturally well drained. On the more sloping areas where clean cultivation has been practiced there has been much sheet erosion and in places a large amount of gully erosion.

Climate.—There is sufficient range in climate to affect growing of certain crops; for example, cotton is grown only in the southern part of this belt. Mean annual temperature for the northern part ranges from 57° to 60° F., rainfall 49 inches; in the southern part the mean temperature is from 60° to 63°, rainfall 48 inches. Average length of frost-free season in the northern part is 180 days as contrasted with 230 days in the southern part.

Native vegetation.—Original growth was hardwoods and shortleaf pine. Present growth is mainly old-field pine, together with some white, post, red, and blackjack oaks, hickory, dogwood, sourwood, red gum, poplar, willow, cedar, and persimmon.

Parent materials.—Soils underlain by and derived from fine-textured rocks—Carolina slates and associated rocks, and dark-colored basic rocks.

Soils.—Soils are characterized by their silty texture and smooth flourlike feel; they are the only large areas of silt loam soils developed in the Piedmont. They are low in organic matter and are medium to strongly acid in reaction. Georgeville soils have grayish-yellow or light-red surface soil and light-red smooth silty clay subsoils which at about 3 to 4 feet become lighter colored and very friable and grade into the soft disintegrated slate. The Alamance soils differ from the Georgeville in having light-gray surface soils and yellow friable silty clay loam subsoils. The Herndon soils are intermediate in color between the Georgeville and Alamance, whereas the Goldston soils have an imperfectly developed subsoil and the Orange soils are characterized by a plastic clay subsoil. Fragments of thin platy slate and angular fragments of slate and white quartz are present locally over the surface. Included with the soils of this region are areas of Cecil, Davidson, Iredell, Appling, Mecklenburg, and Durham soils, which have been described under the Cecil-Appling soil area.

Use.—Over the greater part of this area the farms are small, operated by the owners with only a small outlay for labor, and self-sufficing agriculture is practiced. With the exception of cotton in the southern part, there is no main cash crop. The principal crops grown are corn, wheat, oats, vetch, cowpeas, clover, lespedeza,

alfalfa, soybeans, sorgo, potatoes, sweetpotatoes, peanuts, apples, peaches, pears, and garden vegetables. Alamance and Georgeville soils are considered excellent soils for the growing of lespedeza. Georgeville soils are capable of being built up to a fair or even high state of productivity. Crop rotations are practiced, and some commercial fertilizer and manure are used or green cover crops are turned under.

Greenville-Magnolia Areas

Geographic setting.—These areas contain the reddest soils in the eastern Coastal Plain. They are largely in southwest Georgia but extend into Florida and Alabama. Small areas in South Carolina are not shown on the map. Surface relief is favorable—mostly nearly level, undulating, or gently rolling—and drainage is good. Some areas are steep and excessively drained, and there is considerable sheet erosion and gullying. Elevation ranges from 250 to 400 feet above sea level.

Climate.—Warm-temperate. Short mild winters; long summers. Rainfall about 50 inches; mean temperature 66° F.; frost-free season 240 to 250 days.

Vegetation.—Longleaf and loblolly pines with a mixture of oaks, some hickory, poplar, and dogwood.

Parent materials.—Soils are developed from impure limestones or beds of noncalcareous heavy sandy clays and clays of the Vicksburg formation.

Soils.—Surface soils are predominantly sandy, contain a moderately low content of mineral plant nutrients and organic matter, and are mildly to strongly acid in reaction. Greenville and Blakely soils have brown to reddish-brown surface soils and red to deep-red, or maroon, heavy sandy clay subsoils. Magnolia soils differ essentially from the Greenville in having light-brown to gray surface soils and yellowish-brown subsurface layers. In the flatter areas and slight depressions are the Grady soils, which are gray in the surface portion and have mottled subsoils. Associated with the Greenville-Magnolia soils (fig. 15) are areas of Faceville, Orangeburg, Norfolk, Tifton, and Ruston soils, all of which are good agricultural lands, and small areas of Susquehanna soils.

Use.—The Greenville, Magnolia, and similar soils have always been considered the strongest and most fertile soils in this part of the country. They were important cotton-producing soils before the coming of the boll weevil. Today they are used for the growing of cotton, peanuts, shade-grown cigar-wrapper tobacco, corn, oats, soybeans, velvetbeans, peaches, and pecans on a commercial scale. Shade-grown tobacco is heavily fertilized. The pecan industry in southwest Georgia was developed largely on these soils. They lend themselves to a diversified agriculture and are capable of being built up to a fair state of productivity.

Hanceville-Conway Areas

Geographic setting.—Hanceville, Conway, and associated soils occur largely in an area in the Ouachita province of west-central Arkansas and eastern Oklahoma, a physiographic province of rolling, hilly, or mountainous timbered land, lying 500 to 1,000 feet or more above sea level. A smaller area—the cross timbers of central Oklahoma—is a north-south belt of rolling, hilly, or ridgy land with much timber, lying between two large prairie areas. Only a small proportion of the land is under cultivation and the average standard of living is comparatively low.

Climate.—Warm-temperate and humid. Average annual rainfall 35 to 50 inches—generally ample for crop production. Summers, long and rather hot; winters, short and mild. Frost-free season 200 to 220 days.

Native vegetation.—Largely oak, with intermingling of pine in places.

Parent materials.—Sandstones and shales, in places interbedded. Sandy materials predominate.

Soils.—Probably about one-third of the land is fairly smooth upland and has deep soils, about one-third shallow, stony, and gravelly soils, about one-sixth rough stony land, and about one-eighth to one-sixth alluvial bottom lands. On smooth land the rocks have weathered deeply and the soils are largely fine sandy loams over mellow, crumbly clay subsoils, and moderately productive. On the large areas of steeply sloping, hilly, and mountainous land the soils are thin, stony, of rather low productivity, and in many places nonarable.

Hanceville and Conway soils which are on the uplands are the most extensive. Hanceville soils have brown or grayish-brown surface soils, grading downward

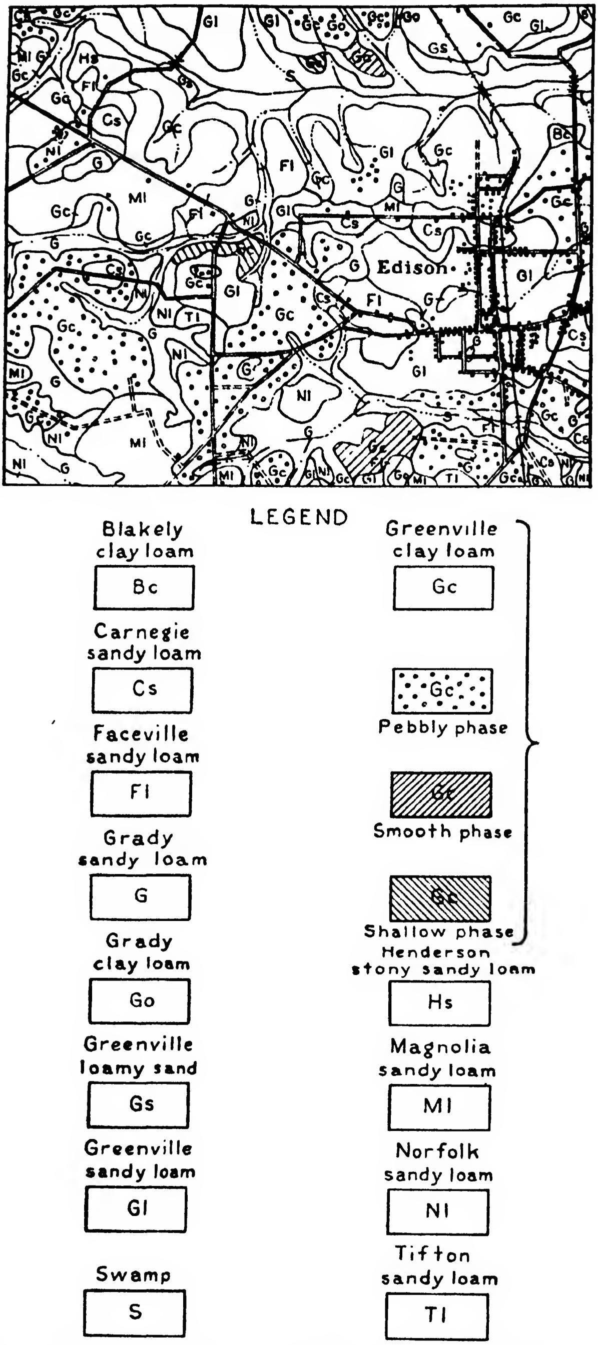

FIGURE 15.—A section of the soil map of Calhoun County, Ga., showing soils of the Greenville-Magnolia association.

into reddish-yellow fine sandy loam and lower into fairly friable red sandy clay or silty clay. Conway soils have lighter colored surface soils and the subsurface and subsoils are yellow, rather friable sandy clays.

The alluvial soils of the bottom lands along streams are much less extensive but are highly productive and economically important. They include the Yahola, Pope, Miller, Lonoke, Atkins, Perry, Portland, and Casa soils. In the larger valleys are small areas of second bottoms or terraces which are smooth and have deep fairly productive soils, chiefly Riverton, Muskogee, Waynesboro, and Holston.

Use.—Most of the land is in timber or pasture, probably only about one-fifth being under cultivation. The principal crops are cotton, corn, oats, hay, and forage. They are grown largely on the alluvial soils of the valleys where fairly good yields are obtained. The deeper soils of the smooth uplands give fair yields and the steeper, shallower soils produce low yields. Corn yields 15 to 20 bushels an acre on the uplands and about twice that on the alluvial soils. Cotton yields about one-third of a bale on the uplands and one-half to two-thirds of a bale on the better alluvial soils. On smoother areas of stony and gravelly soils in some sections apples, peaches, and other fruits are grown.

Farms are small and subsistence crops are commonly grown for home use. Many of the farms, especially in the uplands, do not allow the maintenance of a high standard of living.

Memphis-Grenada Areas

Geographic setting.—Memphis, Grenada, and similiar or associated soils lie in belts bordering the Mississippi River bottom lands, extending from Louisiana northward to southern Illinois and ranging in elevation from 25 to 650 feet above sea level. The broader belt lies east of the flood plain and 50 to 150 feet above it, forming a distinct bluff. The surface, formerly a smooth plain, has been deeply and intricately cut by streams, and ranges from smooth or undulating to rolling, hilly, and broken, with many long narrow ridges. West of the river these soils occupy comparatively narrow discontinuous belts on terraces, not so high as the eastern belt but above overflow. Here much of the land is smooth or gently rolling, though there are some rolling or rough areas and bluffs bordering the bottom lands. These soils are very erodible, and erosion has caused abandonment of thousands of acres formerly farmed.

Climate.—There is a considerable range in climate. Port Gibson, Miss., has a mean annual temperature of 65° F., rainfall of 53 inches, and frost-free season, 223 days. At Springville, Tenn., the mean annual temperature is 58° F., rainfall 49 inches, and frost-free season 194 days.

Native vegetation.— Northern areas support a growth of white, post, and red oak, walnut, hickory, yellow poplar, maple, black locust, and other trees, whereas in the south there is a mixture of shortleaf pine, beech, various oaks, and some hickory and other hardwoods.

Parent materials.—Soil developed from loess or similar fine uniform stream-deposited soil materials, mainly silt, ranging in thickness over the Coastal Plain material from a very thin covering on the east in Mississippi to as much as 100 to 200 feet in thickness on the west.

Soils.—These soils are characterized by the extremely silty texture of both surface soil and subsoil and a smooth flourlike feel. They are naturally low in organic matter and acid in reaction, although the parent material locally is calcareous at 10 or 20 feet below the surface. The Memphis and Grenada are the two important soils in this area. The Memphis silt loam is a light-brown to brownish-yellow silt loam, mellow and friable, underlain by a buff-colored to brownish-yellow and locally reddish-yellow silt loam to silty clay loam extending to a depth of 5 to 100 or more feet without much change in color or consistence. It erodes very easily. The Grenada soils differ from the Memphis mainly in that the light-brown silt loams are underlain at depths between 12 and 30 inches by a mottled light-gray or bluish-gray and yellow or brown compact silty clay loam locally known as hardpan. These soils occupy smoother surface relief than most of the Memphis soils. In the flat, poorly drained areas the Henry soils have gray or bluish-gray mottled with yellow or rust-brown, compact and hard silty clay loam subsoils or hardpan. The Lexington soils are brown silt loams overlying mottled sandy clay material of the Coastal Plain. Richland silt loam is also an important soil on the smoother relief. Included are large areas of soils developed on the broad second bottoms and terraces and also in the first bottoms. Such soils raise the average value of the cropland of many farms.

Use.—In the southern part of the areas cotton is the important cash crop, and it is grown more or less throughout the greater part of the areas. Corn is the main subsistence crop and is widely grown. Tobacco, clover, alfalfa, wheat, oats, sorgo, sweetpotatoes, redtop, soybeans, cowpeas, and hay are produced. Bermuda grass and lespedeza make a luxuriant growth and afford good pasture. Lespedeza is locally grown for seed. Cattle raising is increasingly important. In the northern part of the areas the farms are small and are operated largely by the owners, whereas in the southern part the farms are larger and the tenant system prevails.

Maury-Hagerstown Areas

Geographic setting.—These soil areas comprise the central basin of Tennessee and the famous bluegrass section around Lexington, Ky., and include two of the best agricultural soils of the uplands east of the Mississippi and south of the Ohio Rivers. General features of the areas are broad, undulating to gently rolling plains, with numerous sinks or slight depressions, and broken and hilly strips near the streams. Elevation ranges from 500 to 1,000 or more feet above sea level. Natural surface drainage is well established. Part of the drainage is through underground passages. Large streams have cut through the limestone and locally are bordered by high precipices and picturesque cliffs.

Climate.—Humid, temperate, continental. At Nashville, Tenn., mean temperature 59° F.; mean rainfall 48 inches; frost-free season 209 days. At Lexington, Ky., mean temperature 55°; rainfall, 43 inches; frost-free season, 188 days.

Native vegetation.—Present forest mainly second growth of hardwoods, including various oaks, some hickory, beech, black walnut, sugar maple, and sycamore. There are some extensive areas of cedar and some locust. Original forest was open-type oak and hickory, with scattered areas of prairies covered with tall grasses and broom sedge.

Parent materials.—Phosphatic limestones, limestones, and shales. Some phosphate is mined.

Soils.—The soils are dominantly heavy textured, consisting mainly of silt and clay, with a relatively high content of mineral plant nutrients and organic matter, medium to strongly acid in reaction. Maury and Hagerstown soils have rich brown surface soils, over light-brown to reddish-brown, fairly heavy silty clay loam to clay subsoils, easily penetrated by air, water, and plant roots. Maury soils differ essentially from Hagerstown soils in that they contain a high content of phosphorus.

Soils included are the Mercer, Eden, Salvisa, Loradale, and Lowell, with light-colored surface soils, and yellow to brownish-yellow heavy plastic clay subsoils. There are extensive areas of stony or glade land, especially in the Tennessee basin—one of these is called the Cedars of Lebanon.

Use.—Dominant crops are corn, wheat, oats, rye, barley, alfalfa, Burley tobacco, and Sudan grass. Bluegrass is the dominant pasture grass. Production of bluegrass seed and dairying are important. Horses, mules, beef cattle, sheep, and hogs are raised. Raising and training of race horses is a leading livestock enterprise, particularly around Lexington, Ky. Land use is rather efficient; the better lands are being devoted to the production of tobacco and staple crops, whereas the poorer lands, steep slopes, and stony areas are used for pasture and forestry.

Norfolk-Blanton Area

Geographic setting.—This large area in central Florida includes the well-known lake region and the main citrus-producing section. The land is dominantly undulating to gently rolling with some almost level areas and some that are hilly. There are cypress swamps in places and the country is conspicuously dotted with thousands of small and several large lakes. In elevation this area ranges from 40 to 300 feet above sea level, including the highest elevation in Florida, namely 324 feet on Iron Mountain, the location of the Bok Tower. Drainage is good to excessive over the area except in the flatter and slight depressions. There are few perennial streams and most of the drainage is subterranean.

Climate.—Warm, almost semitropical. Warm winters; long summers. Average annual rainfall 50 inches; mean annual temperature 72° F. Rainy season May to October; dry season November to April. Frost-free season 300 days, and in the southern part only a few or no killing frosts may occur.

Vegetation.—Scattered longleaf pine, turkey oak, blackjack oak, scrub live oak, on well-drained soils, and cypress in the swamps.

Parent materials.—Beds of marine-deposited fine sands overlying fine sandy clay material.

Soils.—Outstanding features of the soils are the extremely sandy texture, loose open consistence, very low content of mineral plant nutrients, small amount of organic matter, and strongly acid reaction. Norfolk fine sand is the predominant type and consists of a light-gray or yellowish-gray fine sand underlain at a few inches by a yellow loose fine sand which at 3 or 4 feet grades into brownish-yellow loose fine sand and at 5 to 10 feet is usually underlain by mottled yellow, light-gray, and brown fine sandy clay. Blanton soils differ from the Norfolk in being lighter colored in both surface and subsoil. There are a few areas of Eustis fine sand—a brown fine sand underlain by reddish-yellow to yellowish-brown fine sand; areas of poorly drained dark-colored soils, including Portsmouth, Scranton, Bladen, and Parkwood; areas of Leon soils, characterized by the hardpan layer; small areas of white loose incoherent sand of the St. Lucie series; and numerous areas of swamp, muck, and peat.

In the vicinity of Gainesville, Ocala, and Brooksville are rather large areas of Hernando, Fellowship, and Gainesville soils. These have sandy surface soils with moderately heavy to heavy plastic clay subsoils, underlain by limestone—phosphatic limestone in places. General farm crops are common to the region, and peanuts and tung oil are produced.

Use.—Citrus-fruit growing ranks first in importance. Most of the oranges and grapefruit grown in Florida are produced on the Norfolk and Blanton sands. Trees are heavily fertilized and some are irrigated. In addition, some corn, cowpeas, velvetbeans, loquats, kumquats, figs, watermelons, sweetpotatoes, sugarcane, and a variety of truck crops are grown. Most of the truck crops are on the poorly drained soils. Crotalaria is extensively grown in the citrus groves as a soil improver. The agriculture is specialized, and soils are used to good advantage, climate being the important factor. There are large areas of similar soils that could be developed for citrus production when market demands and price warrant their use.

Norfolk-Ruston Areas

Geographic setting.—The Norfolk, Ruston, and similar or associated soils occupy a broad belt of land comprising the larger part of the Atlantic and Gulf Coastal Plains, extending from near Fredericksburg in Virginia, across North Carolina, South Carolina, Georgia, northern Florida, Alabama, Mississippi, northern Louisiana, southern Arkansas, eastern Texas, and into the southeast corner of Oklahoma. This part of the Coastal Plain lies above the flatwoods section and ranges from 75 to 500 feet above sea level. It is cut by many large rivers and many smaller streams. The surface of the land over much of this belt ranges from nearly flat to undulating or gently rolling and is favorable for agricultural purposes, but in places, especially in the higher parts in Georgia, Alabama, Mississippi, Arkansas, Louisiana, Texas, and Oklahoma the land is hilly and broken and subject to severe sheet and gully erosion. Drainage is good or excessive except in some of the flat areas and slight depressions.

Climate.—Warm-temperate and humid. Winters mild in southern portion, cool in northern portion. At Nashville, N. C., mean annual temperature is 60° F., rainfall 48 inches, well distributed, and frost-free season 200 days. At Evergreen, Ala., mean temperature is 65°, rainfall 51 inches, frost-free season 246 days. At Hallettsville, Tex., the mean temperature is 69°, rainfall 32 inches, and frost-free season, 262 days.

Vegetation.—Present growth longleaf and shortleaf pine, blackjack, post and white oaks, with some dogwood, sourwood, sweetgum, and hickory on well-drained areas; in poorly drained situations gums and cypress predominate. Toward the western edge of the belt in Texas oaks are dominant.

Parent materials.—Soils are derived from unconsolidated beds of sands, sandy clays, and clays, and these materials have influenced the soil profile as regards the texture and consistence.

Soils.—Climate, vegetation, and character of the soils have not favored the accumulation of organic matter; therefore soils are light-colored, dominantly sandy in the surface portion, ranging from coarse sands to fine sandy loams, and are medium to strongly acid in reaction. The soils of the Norfolk series are the

most widely distributed and they have yellowish-gray to light-gray sandy soils and yellow friable sandy clay to sand subsoils which are underlain at about 23 to 40 inches by mottled light-red, yellow, and gray sandy material. The Ruston soils are light gray to grayish brown and have reddish-yellow to yellowish-brown friable sandy clay or sand subsoils. Closely associated with the Norfolk and Ruston soils are the Red Bay and Orangeburg soils, which have red to gray surface soils and red friable subsoils. On the second bottoms and terraces are areas of Kalmia, Cahaba, and Amite soils which are considered good agricultural lands.

In the Norfolk-Ruston area an important group of good agricultural soils comprise the Marlboro, Faceville, Magnolia, Greenville, Bowie, and Segno soils. These contain more fine material throughout the soil and subsoil and are underlain by heavier material than the Norfolk and Ruston soils. Included are also scattered areas of Susquehanna, Cuthbert, Kirvin, Nacogdoches, and Luverne which have heavy dense clay subsoils but are well drained. In poorly drained situations are small areas of Portsmouth, Grady, Myatt, and Plummer soils which range

FIGURE 16.—Cotton on Norfolk fine sandy loam. Farm and tenant houses in the background. The Norfolk fine sandy loam and sandy loam are the best soils in the Coastal Plain for the production of bright-leaf tobacco and peanuts and among the best for cotton.

from black to gray in the surface portion and all have mottled sandy clay to clay subsoils.

Use.—The agriculture of this region is based largely on the production of three important money crops—cotton, tobacco, and peanuts. Truck crops are grown locally. There is a large number of commercial orchards of pecans and peaches. A small acreage is devoted to the production of sweetpotatoes, watermelons, cantaloups, sugarcane, scuppernong grapes, pears, figs, and garden vegetables. Corn is the dominant subsistence crop and is the most widely grown of any crop in the region. Lespedeza and Bermuda grass are the main pasture grasses. Oats, wheat, cowpeas, velvetbeans, soybeans, crimson clover, and Austrian Winter peas are produced as subsistence crops and for hay.

Much of the soil is used to good advantage and excellent crop adaptation is practiced. The tenant system prevails; commercial fertilizers are applied in large quantities to tobacco, cotton, and truck crops (fig. 16). The soils of this region are low in mineral plant nutrients and organic matter but many of them possess such favorable physical properties that they respond readily to fertilization and produce the most profitable crops of any soils in the South. Many of

these soils are so handled as to provide a good to high standard of living for the farmers, though some of the poorer soils or those where improved methods are not used provide only a very meager living.

Norfolk Sands Area

Geographic setting.—Norfolk sands comprise the well-known sand-hill region of the South, a belt extending from near Columbus, Ga., to Sanford, N. C., attaining the greatest width in North Carolina. This area presents a rather conspicuous landscape, as the country rises higher than either the Piedmont or the typical Coastal Plain. Topography is quite variable, ranging from almost level to steeply sloping and hilly. Both surface and internal drainage are good to excessive.

Climate.—Temperate to warm. Mean annual temperature ranges from 62° to 64° F.; rainfall, from 47 to 50 inches, for the northern and southern portions

FIGURE 17.—Pruned peach orchard on Norfolk sand.

respectively. The climate is healthful, and many tourists spend the midseason in Pinehurst, Aiken, and Augusta.

Vegetation.—Present growth is scattering longleaf pine, thick growth of small turkey, forked-leaf, and blackjack oaks. Originally heavily forested with longleaf pine.

Parent materials.—Beds of sand, probably old marine beach, underlain by variegated light-red, yellow, gray, purple, and white sandy clay material.

Soils.—Mainly sands and coarse sands with smaller areas of sandy loams. Soils inherently low in mineral plant nutrients and organic matter. Strongly acid in reaction. The Norfolk sands are yellowish gray to light gray underlain by yellow to pale yellow loose incoherent sands to a depth of 3 to 80 feet. The included areas of Norfolk, Ruston, and Orangeburg sandy loams are developed on the smoother relief and are underlain by sandy clay material within 3 feet. In the vicinity of Aiken, Johnston, and Batesburg, S. C., and in a few other localities are several almost level areas of Orangeburg, Marlboro, Red Bay, and Magnolia soils. They occur on high plateaulike areas, comprise some of the best agricultural soils in the Coastal Plain, and are conspicuous landscapes in the Sand Hill

area. On the steep slopes are areas of Hoffman sandy loam where the sand is underlain by the parent material anywhere between 6 and 30 inches.

Use.—Probably 20 percent of the Norfolk sand area has been cleared. The cash crops are peaches, dewberries, grapes, cotton, and tobacco, whereas the subsistence crops are corn, rye, oats, sweetpotatoes, watermelons, sorgo, peanuts, cowpeas, lespedeza, and velvetbeans. Yields are very low unless large amounts of fertilizers or manures are applied (fig. 17). By far the greater part of the Norfolk sands should be reforested or used for wildlife or recreational purposes. Only the smoother areas and those where the sandy clays are near the surface should be farmed.

Susquehanna-Savannah-Ruston Area

Geographic setting.—This is the higher and locally more dissected part of the Gulf Coastal Plain and covers an area known as the clay hills in central and northwestern Alabama, northeastern Mississippi, western Tennessee, and southwestern Kentucky. Elevations range from about 400 to slightly more than 600 feet above sea level. Relief ranges from almost level to hilly and broken. Good surface drainage prevails, but internal drainage is hindered in those soils having heavy subsoils and hardpan. Both sheet and gully erosion have been active, especially on the hilly areas of Susquehanna, Cuthbert, and Kirvin soils, and part of the region is extremely dissected.

Climate.—Warm to temperate; considerable range in growing season. In Bullock County, Ala., mean annual temperature is 64°, rainfall 54 inches, frost-free season 240 days; whereas in Henry County, Tenn., mean annual temperature is 58°, rainfall 49 inches, frost-free season 194 days.

Native vegetation.—In northern end of area post, red, and white oaks, some hickory, elm, black gum, and cedar. In southern part, longleaf and shortleaf pine with some hardwoods.

Parent materials.—Unconsolidated beds of sandy clays and heavy clays of the Coastal Plain. Deposits of clays, sands, and gravel give rise to Guin soils, undifferentiated.

Soils.—There are a large number of different soils in this area. They range from sandy loams through silt loams to heavy clays, are dominantly low in organic matter with no extensive areas of sand, medium to strongly acid in reaction, and with subsoils prevailingly heavier than in the Norfolk-Ruston area. Susquehanna soils have grayish-yellow fine sandy loam or reddish-brown clay surface soils and mottled red, yellow, and gray heavy plastic clay subsoils. The Cuthbert and Kirvin soils closely associated in occurrence and parent material with the Susquehanna soils have tough, compact, clay subsoils. The Savannah soils are gray to grayish yellow, with brownish-yellow friable subsoils and a hardpan layer anywhere between 18 and 30 inches below the surface. They are developed on comparatively smooth interstream areas mainly to the north of the so-called prairie belt. Atwood soils, associated with the Savannah, resemble the Ruston soils in color but contain more fine material throughout the profile and locally have slightly compact subsoils. The Ruston soils are important in this area and these have been described under the Norfolk-Ruston area. The Red Bay, Akron, Luverne, Orangeburg, and Norfolk soils are developed to a small extent. In the flatwoods area extending across the northeastern part of Mississippi are the Lufkin soils, with light-gray surface soils and tough to plastic clay subsoils. Included also are small areas of the so-called brown loam or Grenada soils and also areas of Lexington soils. There are areas of good farming soils on the broad first and second bottoms. The Lauderdale and Guin soils constitute rough and broken, and also some stony and rock land and are best suited to forestry.

Use.—The agriculture is similar in many respects to that on the Norfolk and Ruston soils. Cotton is the dominant and locally the only cash crop. The subsistence crops are corn, oats, forage crops, sweetpotatoes, sorgo, and sugarcane. Considerable acreage is devoted to cowpeas, soybeans, velvetbeans, and Austrian Winter peas. Lespedeza, Bermuda, and carpet grass are principal pasture grasses. Special crops grown on a commercial scale are strawberries, watermelons, pecans, and peaches. Large areas are severely eroded and gullied and are abandoned and reforested to longleaf and shortleaf pines. Commercial fertilizers are used on cotton and to a less extent on other crops.

Tifton-Irvington Area

Geographic setting.—The Tifton, Irvington, and associated soils known as red pebbly lands are developed in the so-called wire-grass section of southwest Georgia with scattered areas (not shown on the map) in Alabama, South Carolina, and Florida. Elevations range from 300 to 400 feet above sea level. The surface is almost level, undulating or gently sloping, and lies favorably for agricultural operations. All areas of Tifton soils are naturally well drained.

Climate.—Warm-temperate. Short mild winters; long hot summers. Mean annual temperature about 63° F. Rainfall about 49 inches, well distributed. Average frost-free season 246 days.

Native vegetation.—About 80 percent cleared—longleaf pine, with scattering oaks and hickory. Undergrowth of bunches of tall wire grass. Original forest, magnificent longleaf pine.

Parent materials.—Unconsolidated beds of mottled red, light-gray, yellow, and purple, hard but brittle, sandy clay material.

Soils.—Outstanding characteristics are the large quantities of small rounded brown to almost black concretions one-eighth to one-half inch in diameter on the surface, in the surface soil, and to a less extent in the subsoil; the deep-yellow color and friable consistence of the subsoils; and the medium to strongly acid reaction. Tifton soils, the dominant soils of the area, have grayish-brown to gray loamy sand surface soil 4 to 6 inches deep; subsurface layer of yellow to brownish-yellow light textured sandy loam; and subsoil, beginning at 8 to 15 inches and extending to 30 to 36 inches, of yellow, brownish-yellow, or faintly reddish-yellow firm but friable sandy clay. Below this the material is slightly compact and more or less mottled. Irvington soils, which are not extensive, differ from the Tifton in having a compact or cemented layer below the subsoil. Included are areas of Norfolk, Ruston, and Blanton soils closely related in surface relief, drainage conditions, and general use. In depressions and at the bases of slopes are areas of Grady and Plummer soils, with gray surface soils and mottled subsoils. They are poorly drained and are used for pasture and forestry. There is very little erosion in this area except on the steeper slopes.

Use.—Cotton is the cash and dominant crop. Corn is the main subsistence crop. Others are oats, peanuts, velvetbeans, cowpeas, Austrian Winter peas, watermelons, sweetpotatoes, cabbage, tobacco, lespedeza, and garden vegetables. Considerable acreage is devoted to pecans and peaches. Most of the crops are fertilized.

Tifton soils are considered uniformly good agricultural lands. A fair standard of living is obtained from the land and practically a self-sufficing agriculture can be maintained.

Tishomingo-Pontotoc Area

Geographic setting.—Tishomingo, Pontotoc, and associated soils occur in the central basin, an area of about 2 million acres of comparatively low but rolling land in central Texas, surrounded by limestone areas which are several hundred feet higher. The basin ranges from 1,000 to 1,500 feet above sea level. It is an area largely of shallow stony soils, and large farms or cattle ranches. Only a small amount of land is cultivated.

Climate.—Warm-temperate and humid or subhumid. Summers are long and hot; winters, short and mild. Rainfall is rather irregular and averages about 30 inches annually. There are occasional periods of drought.

Native vegetation.—Largely live oak and other species of oak. Some thinly timbered sections with scattered growth of trees and shrubs, such as mesquite.

Parent materials.—Schist, granite, and sandstone. Some small areas from limestone.

Soils.—Varied, but mostly red and sandy, with some included areas of dark-colored Prairie soils. Large areas are shallow, stony, and nonarable, but smoother areas of deeper soils are quite productive.

Use.—Only about 5 percent of the land is used for crop production. Most of it is range pasture and is included in large livestock farms and cattle ranches. Some sheep and goats are raised in places. The better soils are only moderately productive and crop production is often limited by drought. Practically no commercial fertilizer is used, as there is not sufficient assurance of a satisfactory financial return from its use. Measures are needed to protect cultivated land from destructive erosion.

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White Store-Granville Areas

Geographic setting.—The White Store, Granville, and associated soils occupy small areas in central and northern North Carolina and southern Virginia. They occupy basinlike areas which were at one time covered by inland seas, and lie lower than the typical Piedmont. The land ranges from undulating or gently rolling to rolling and hilly. Elevation ranges from about 360 to 480 feet above sea level. Natural surface drainage is good but internal drainage on some soils is extremely slow due to the heavy plastic consistency of the subsoils. Erosion has practically ruined large areas of the White Store soils, not only removing the surface soils but also forming shallow gullies down to bedrock.

Climate.—Warm-temperate. Mean annual temperature 60° F.; rainfall 44 to 48 inches; frost-free season about 192 days. Average depth of snowfall 12 inches.

Native vegetation.—Present forest, second growth of shortleaf and old-field pines, together with black, red, white, post, and blackjack oaks, and a few hickory, dogwood, sourwood, cedar, and poplar trees.

Parent materials.—Red and gray sandstones, shales, mudstones, or pelite of Triassic age.

Soils.—Soils are prevailingly light in color and low in organic matter and mineral plant nutrients. Medium to strongly acid in reaction. Granville soils have light gray to yellowish-gray surface soils and yellow friable sandy clay subsoils. Textures range from coarse to fine. White Store soils differ from the Granville in having mottled gray, yellow, purplish-red, and whitish heavy plastic fine sandy clay or clay subsoils. Wadesboro soils have brown surface soils and light-red friable subsoils, whereas the Penn have purplish surface soils and purplish-red shallow subsoils.

Use.—These soils are used for the production of corn, cotton, bright-leaf tobacco, wheat, oats, cowpeas, soybeans, sweetpotatoes, sorgo, watermelons, cantaloups, vegetables, apples, peaches, and pears. Cotton and tobacco are heavily fertilized.

Windthorst-Nimrod Area

Geographic setting.—Windthorst, Nimrod, and associated soils occupy the West Cross Timbers section, an irregular north-south belt of rolling timbered land, extending from north-central Texas to south-central Oklahoma, a distance of several hundred miles.

Climate.—Warm-temperate and humid, though near the western limit of the humid region. Rainfall is irregular, though normally sufficient for crop production. It averages about 28 to 35 inches annually in various parts of the area. Summers are long and hot; winters short and mild.

Native vegetation.—Chiefly post oak and blackjack oak, with some hickory and other trees.

Parent materials.—Weathered residue of sandstone.

Soils.—The soils are mostly light colored and sandy, and many areas are shallow and stony. In places they are subject to severe erosion if not properly handled.

Windthorst, Stephenville, and Nimrod soils are the most important soils of this area. They are developed mostly from fairly deeply weathered rock materials, though in places this material is thin. Windthorst soils have light-colored surface soils over heavy red clay subsoils. Stephenville soils are similar to the Windthorst but have friable red sandy clay subsoils. Nimrod soils lie on smooth land and are deeply leached, very sandy soils with very light colored surface soils and yellow, soft, pervious subsoils. The Nimrod soils are subject to blowing and drifting in places and are locally referred to as blow sand. Windthorst and Stephenville soils are more extensive than the Nimrod. They are mostly fine sandy loams, though there are stony types and phases which occupy rather large areas.

The alluvial soils are mostly sandy and moderately productive. The Ochlockonee soils are the most important of these.

Use.—Land use is much the same as on other soils of the Red and Yellow soil region, but farms are larger and more livestock is raised than in the more eastern sections where rainfall is heavier. The principal crops are cotton, grain sorghums, sorgo, corn, and other feed crops. In places truck and fruit crops are grown for outside markets. Peanuts are grown commercially in some sections. Steeper and stonier lands are largely nonarable and are in forest and pasture. The alluvial

soils are moderately productive and have a larger proportion of cultivated land than do soils of the uplands.

Erosion has caused and is causing much damage to farm lands, and measures are needed to control it. The soils are not highly productive naturally, but they produce fairly good yields of general farm crops until depleted by erosion or exhaustive cropping. Many farms are badly run down and do not support a good standard of living. Commercial fertilizers are not extensively used, as occasional periods of dry weather during the growing season render their use unprofitable.

CHERNOZEM SOILS

Soils of the Chernozem group are developed in temperate subhumid grasslands. The surface soils are very dark brown to black. The underlying material varies greatly as a result of the influence of parent material, but a distinguishing feature of these soils is an accumulation of carbonates, principally lime carbonate, in the lower part of the solum. The Chernozem soils are developed in a broad belt in the central part of the United States on the tall-grass plains, mainly where the precipitation ranges from 18 to 28 inches. Wheat and other small grains are grown in all parts of the Chernozem belt. Corn is grown successfully in the eastern part of this belt.

Other areas of Chernozem soils are in southeastern Washington, northeastern Oregon, and northern Idaho. These are shown on the map as Palouse soil areas. Wheat is the principal crop.

Boyd-Holt Areas

Geographic setting.— Areas bordering the Missouri River in the south-central part of South Dakota and the north-central part of Nebraska have soils differing in character and productiveness from the surrounding country. The soils are developed where the Missouri River has cut into and exposed the lower rocks. The surface features are variable, ranging from gently undulating divides, which occupy a comparatively small part of the surface, to strongly rolling and hilly slopes along the streams. Elevation ranges from about 1,500 to 2,500 feet above sea level.

Climate.—Mean annual precipitation 20 inches. Average length of frost-free season about 145 days. Average crop yields reduced by deficiency of rainfall.

Native vegetation.—Both tall and short grasses, consisting chiefly of grama, buffalo grass, and wheat grasses.

Parent materials.— Boyd soils are developed over Cretaceous shales mainly of the Pierre formation, and Holt soils over calcareous Tertiary sandstones.

Soils.—The Boyd soils are characterized by very dark brown to almost black granular surface soils and heavy olive-brown subsoils. Lime has accumulated at a depth of 1 to 2 feet. The soil is underlain at a depth of 2 to 4 feet by dark olive-gray shale of the Pierre formation. Both soils and parent materials contain selenium in small quantities. These soils differ from the Pierre soils which occur further west in having deeper and darker surface layers. The Holt soils comprise small areas where limy sandstones are on or near the surface. The surface soils are very dark grayish-brown to black. On nearly level areas they may be 10 to 14 inches thick, but over the greater part of the region they are thinner. The subsoils range downward from grayish brown to nearly white. The unweathered parent rock lies within a depth of 4 feet.

Use.—The smoother areas of these soils are used chiefly for the production of oats, barley, and corn. Yields are similar to those of the best soils of this climatic belt, being decreased in most years by lack of moisture. The rolling areas which make up the greater part of the region are used mainly as pasture for cattle. Some trouble has been experienced, especially on the Boyd soils, from selenium poisoning of livestock. The problems of the farmer in soil management are to reduce wind erosion and to conserve the moisture supply.

Barnes-Parnell Area

Geographic setting.—The upland soils of this area, in North Dakota, South Dakota, and western Minnesota, are of particular interest for the reason that they

have developed a darker surface layer than any other upland soils in the United States. Here condition of climate and vegetation combine to favor the accumulation of large amounts of black organic matter in the surface soils. The soils, features of the landscape, native vegetation, and crops are comparatively uniform over the area. The topographic features are largely constructional, consisting of a succession of smooth, nearly level glacial till plains and low rounded morainic hills and ridges with occasional enclosed lakes or marshy areas. The few streams flow mostly in a north and south direction through shallow valleys. The range in elevation is from about 900 feet in the eastern part of North Dakota to more than 1,600 feet in the western part of the belt.

Climate.—Subhumid, with long cold winters and short summers. Mean annual temperature ranges from 36° to 46° F. Precipitation decreases westward across the southern part from 24 to 20 inches, and across the northern part from 24 to 17 inches. Average number of days without killing frost ranges from 110 in the northern part to 140 in the southern part. Hot winds and intense heat in summer occasionally damage crops.

Native vegetation.—Tall grasses, now largely replaced by cultivated crops.

Parent materials.—Calcareous glacial drift of the Wisconsin stage. The drift

FIGURE 18.—Corn on typical Barnes loam.

reworked and redeposited in poorly drained areas, is the parent material of the Parnell soils.

Soils.—The dominant soil is Barnes loam. The surface layer is a black loam which varies in thickness on the smooth upland from 10 to 15 inches. This is underlain by a layer of brown loam 4 to 12 inches thick. The next lower layer, the zone of lime accumulation, consists of light grayish-brown or almost white material in which the lime occurs as concretions or in finely divided form. Highly calcareous glacial drift lies below the lime zone. The next most extensive soils of the area are the silt loam and the sandy loams of the Barnes series. They differ from the loam mainly in the texture of their surface soils. The Parnell soils are waterlogged associates of the Barnes and occur in nearly all parts of the area in poorly drained depressions. In the central parts of North Dakota and South Dakota, small areas of so-called claypan soils have developed within the areas of Barnes soils through the action of small amounts of alkali salts. Where these claypan areas occupy more than half the surface they have been indicated on the soil maps as the Beadle soils.

Use.—In this area, which is an important part of the spring wheat belt, wheat is nearly everywhere the principal crop. In the southern part of South Dakota and in Minnesota, wheat has been partly displaced by corn, oats, barley, and hay incidental to the development of dairying and stock raising (fig. 18). In the northern part of North Dakota, small grains, chiefly wheat, are grown almost exclusively. The Parnell soils are used mainly for pasture and hay land, for which they have a low value.

Fargo-Bearden Areas

Geographic setting.— The soils of these areas have developed on the soil material filling old lake basins. The largest body of these soils, known as Red River Valley, which occupies western Minnesota and eastern North Dakota, is the filled-in basin of glacial Lake Agassiz. It comprises extensive areas of level land, being one of the largest bodies of level land in the world. In extremely rainy seasons the surplus water can be drained from the land only very slowly. Another and better drained lacustrine area lies along the valley of James River in South Dakota. Elevation ranges from about 800 to 1,200 feet above sea level.

Climate.—The climate is subhumid and characterized by long cold winters and short summers. The mean annual precipitation is 20 inches, and about one-half of this falls during May, June, and July.

Native vegetation.- The areas were formerly covered with a dense grass vegetation. Strips of forests on the valley slopes and a few clumps of poplar and other trees had secured a place. The sloughs and poorly drained areas were covered by a rank growth of sedges and grass.

Parent materials.--The lacustrine deposits of Red River Valley are in three belts: In the lower part along Red River is a belt of clays and clay loams; next, a belt of silt loams; and on the outer edge, a belt of sandy loams. The soils developed over the clays and clay loams are the Fargo soils; those over the silty material, the Bearden soils; and those over the sandy deposits, the Ulen soils. The Bearden soils are also extensive in the James River area.

Soils.—The surface layers of the Fargo soils are black and are usually very heavy in texture. They range in thickness from 10 to 20 inches. Below this is a gray or olive-gray calcareous clay. Below a depth of 24 to 30 inches the soil is underlain by olive and gray calcareous lacustrine clay. The Bearden surface soils are silt loams or very fine sandy loams, underlain at a depth of 12 to 24 inches by gray silt loam. Below a depth of 30 inches the substratum becomes more sandy, being usually a silty very fine sandy loam. Associated with these are the sandy loams and sands of the Ulen series, poorly drained soils of the Tanberg series, and comparatively small areas of soils developed over beach gravels and glacial drift.

Use.- These areas are noted for their production of small grains. Wheat is the principal crop, with oats and barley next in importance. Corn and flax are also grown. A large acreage of poorly drained land is used for hay. The tendency at present is toward a decrease in the acreage devoted to wheat and an increase in that of other crops. The natural productivity of the soils is reduced by damage from droughts and occasionally in a wet season by lack of adequate drainage. Much power is required to plow the heavier soils and they must be plowed when moisture conditions are favorable, preferably in the fall. If properly plowed they make a good granular seedbed.

Hays Area

Geographic setting.- -The Hays and associated and similar soils occupy a large area in central Kansas. The southern part of this area is a smooth, flat to undulating plain, broken at wide intervals by the shallow valleys of eastward-flowing streams; in the northern part the streams have cut more deeply into the plain and the rolling stream slopes occupy a large part of the total area. Much of the land in the northeast is rough. The smooth surface of much of the country permits the use of labor-saving machinery in the production of small grains. Elevation ranges from about 1,500 to 2,200 feet above sea level.

Climate.—Precipitation decreases westward from 30 to 22 inches. The mean annual temperature near the center of the region is about 54° F. The average number of days without killing frost is about 170.

Native vegetation.---Tall grasses, of which bluestem and bunch grass are dominant. Along the western edge grama and buffalo grass are abundant. Hardwood trees grow along the stream channels. Tree shelterbelts and wood lots have been planted on many of the farms.

Parent materials.—In the greater part of the area the soils are developed over shales and limestones of Cretaceous age. In the northeastern part Cretaceous sandstone of the Dakota formation is the parent material.

Soils.—The soils of the area as a whole have not been studied in detail. They differ somewhat from the silty claypan soils of the Crete-Hastings-Idana area

Near Hays, Kans., the surface soil is dark grayish brown, noncalcareous, silty clay loam; the subsoil is very dark brown, or nearly black, clay with prismatic structure, overlying tough olive-brown clay. The zone of lime accumulation begins at a depth of 30 inches.

The surface soils of the Hays soils of the smooth plains range in texture from silt loams to clays. In the hilly to broken country in the northeast, however, the soils are sandy and thin.

Use.—The smoother land is well suited to general farming with production of wheat, alfalfa, sorghums, and, in the especially favorable localities, corn. The alluvial soils along the larger streams are very productive, especially of corn. In the northeast the rough land with shallow sandy soils is used largely for grazing. Farming in the area as a whole has proved successful. Despite occasional crop failures in dry years, the average production has been sufficiently high to establish a type of permanent agriculture. The principal problems of soil management are conservation of moisture and protection of the soil from erosion.

Holdrege-Hall Area

Geographic setting.—Central and south-central Nebraska and the adjacent part of Kansas are occupied mainly by Holdrege soils on the uplands and Hall soils on the terraces. This area, like those adjoining it on the east and west, is part of a generally smooth though well-drained loess-covered plain characterized as a whole by shallow, widely spaced valleys with gradually sloping sides, modified in places by a series of narrow flat-topped upland tongues separated by canyonlike drainage ways. Elevation ranges from about 2,200 to 3,000 feet above sea level. The principal distinguishing features of this area are those imposed by the climate on the soils and vegetation. The vegetation is more luxuriant than in the drier Keith area to the west and the dominant soils are darker colored. They have suffered less downward translocation of clay from surface soil to subsoil than has occurred in the moister Crete area to the east, and their subsoils lack the claypan character of the Crete soils.

Climate.—The mean annual precipitation in this area decreases from about 26 inches in the east to about 22 inches in the west. The average summer and winter temperatures are 75° and 25° F., respectively. The number of days free from killing frosts ranges from 150 in the northern part to 170 in the southern part of the region.

Native vegetation.—Mixed tall and short grasses with big and little bluestems and needlegrass dominating in the eastern part of the area, and grama and buffalo grasses dominating in the western part.

Parent materials.—Peorian loess, a light-colored, floury, limy silt deposited by the wind, covers all of the area except narrow strips on some of the valley slopes where Pleistocene sands and gravels or calcareous Tertiary rocks are exposed.

Soils.—Holdrege silt loam, a typical Chernozem soil, dominates on the smooth uplands except in scattered small and shallow depressions, which are occupied by heavy, poorly drained Scott and Fillmore soils. Its surface soil consists of very dark grayish-brown friable silt loam. The upper part of the subsoil is dark grayish-brown silt loam, only slightly heavier than the surface layer. The lower part of the subsoil, composed mainly of the lime zone, consists of friable very light grayish-brown or grayish-white calcareous silt or silt loam. The floury Peorian loess usually occurs at a depth of 4 to 6 feet. Tracts of Holdrege very fine sandy loam and Holdrege fine sandy loam may be associated with the silt-loam type in areas adjoining more sandy soils. Immature light-colored soils developing on loess, gravel, or sandstone occur at places on eroded areas along streams. Most of them are highly calcareous. The Hall soils do not differ materially from the Holdrege soils in profile features but owing to their lower position receive more moisture through run-off from higher levels and have a slightly higher agricultural value.

Use.—During seasons of normal or above-normal precipitation the Holdrege and Hall soils are highly productive of the general farm crops grown in the area. Practically all of the area occupied by them is under cultivation. Corn is nearly everywhere the dominant crop, although alfalfa is profitable on both soils and does especially well on the Hall. Winter wheat and sorghums are relatively important in the southern part of the area. Most of the light-colored immature soils on the steeper valley sides are included in native pasture land.

Moody Areas

Geographic setting.—Comparatively small areas in northeastern Nebraska and contiguous States are covered by silty soils which have a high content of lime near the surface. In other respects the areas do not differ greatly from the Tama-Marshall area of Iowa and Nebraska. The land ranges from undulating to sharply rolling, and the elevation from 1,300 to 1,700 feet above sea level.

Climate.—The mean annual precipitation is about 25 inches and a large part of it falls during the growing season. The mean annual temperature ranges from 43° to 47° F.

Native vegetation.—Grasses of tall species on the uplands. In the valleys and on stream bottoms there is a growth of trees, mainly cottonwood, ash, elm, and hackberry.

Parent materials.—Calcareous loess of Peorian age.

Soils.—Moody soils, the most important soils of the areas, have dark grayish-brown to almost black friable surface soils, grading downward into light grayish-brown friable silty subsoils. A well-developed zone of lime accumulation begins at a depth of 18 to 30 inches. A distinguishing feature of this soil is a layer of lime concretions in the upper part of the lime zone. The soil rests on the parent loess at a depth of 24 to 48 inches. With this soil are associated several soils of minor importance. The Flandreau soils are similar to the Moody in the upper part but are underlain by sand or gravel. The Crofton soils have had their surface layers removed by erosion, exposing the upper part of the lime zone with its numerous concretions.

FIGURE 19.—Harvesting wheat on Moody silt loam, Thurston County, Nebr.

Use.—The Moody soils contribute largely to the prosperity of the areas in which they occur. They lie within the Corn Belt and compare favorably with the best corn lands of Iowa. Corn is the principal crop, with oats in second place. Wheat produces well but is not so extensively grown as corn and oats (fig. 19). Alfalfa and sweetclover are successfully grown.

Moody silt loam is very susceptible to erosion by water, and the more sandy types are damaged by wind in dry years.

Palouse Areas

Geographic setting.—Palouse soils occupy rolling uplands in the Columbia Plateau wheat section of Washington, Oregon, and Idaho, in that section commonly known as the Palouse country. They lie at elevations of 1,500 to 3,500 feet above sea level, usually slightly higher than the Walla Walla soils and somewhat lower than the Nez Perce. The land is extensively farmed and rather thinly settled.

Climate.—Subhumid. Rainfall 18 to 22 inches. Summers are dry and moderate or hot; winters; long and cold.

Native vegetation.—Bunch grass and a small amount of brush, including wild rose and snowberry.

Parent materials.—Largely loess (floury wind-borne material); some residual from basalt (lava).

Soils.—Surface soils very dark brown or dark grayish-brown (appearing black when moist), mellow and granular. Silt loam is the predominant texture. Subsoils lighter brown or yellowish brown, typically somewhat heavier and more compact than the surface soils. There may or may not be a concentration of light-gray lime carbonate within 6 feet of the surface. Some areas have very mellow subsoils and resemble the Walla Walla soils. There are included some narrow alluvial bottom lands of very dark-colored mellow soils (Caldwell).

These soils are naturally very fertile but, because of rolling surface and dry-farm practices, are subject to rather severe erosion.

Use.—Mostly large-scale wheat farming (fig. 20). Land summer-fallowed every

FIGURE 20.—Well-prepared seedbed on Palouse soil. This land is used mostly for large-scale wheat farming. The future productivity of this soil depends on maintenance of fertility by proper rotation and by prevention of destructive erosion.

second or third year. Yields are high. Navy beans, peas, timothy, alfalfa, potatoes, and tree fruits are minor crops which do fairly well, but yields are rather low because of the dry summers. Moisture conditions are better on bottom lands, where alfalfa, timothy and clover, potatoes, and pasture grasses thrive.

Contour plowing, plowing under of straw and manure, strip cropping, crop rotation, including the growing of legumes and sod crops, are all desirable practices to maintain productivity of the land and to minimize soil losses by erosion.

CHESTNUT SOILS

Chestnut soils occupy a vast area in the northern Great Plains west of the Chernozem belt and in parts of Washington, Oregon, and Idaho. These soils as developed on the Great Plains are characterized by dark-brown or dark grayish-brown surface soils grading into light-gray or white calcareous horizons at a depth of 1½ to 2 feet. In Oregon and Washington the subsurface layer is brown, and the white calcareous layer lies at an average depth of about 4½ feet. These soils

develop in temperate to cool semiarid regions under a mixed short- and tall-grass vegetation. The principal crops are small grains. The soils constitute a large part of the spring wheat belt. With adequate moisture, they are highly productive, but average yields are lowered by deficient rainfall.

Hyrum-Bingham-Avon Areas

Geographic setting.—The Hyrum, Bingham, Avon, and associated soils occupy belts along the bases of the mountains in the Great Basin and other parts of the western intermountain region in Utah, Idaho, Montana, and northern Washington, at elevations of 2,500 to 6,000 feet. They lie largely on alluvial fans but include areas on lake terraces, stream terraces, and bottom lands. The higher parts of the areas are generally more or less steeply sloping and rolling and are largely treeless dry-farmed or range lands, whereas the lower parts are flatter and are in many places rather highly developed irrigated lands, with many well-built farmsteads surrounded by trees.

Climate.—Semiarid. Rainfall 12 to 18 inches, falling mostly in winter. Early summer showers common in places. Summers rather hot, winters cold. The average length of the frost-free season is 185 days at Salt Lake City, Utah, 135 days at Polson, Mont., and 66 days at Chesterfield, Idaho.

Native vegetation.—Bunch grass and sagebrush. Small amount of mountain maple, scrub oak, serviceberry, and aspen near the mountains.

Parent materials.—Alluvial outwash from mountains, consisting of limestone, quartzite, sandstone, shale, and granite materials.

Soils.—The Hyrum and Bingham soils, developed on alluvial fans, have brown to dark-brown or dark grayish-brown, mellow, granular, gravelly loam topsoils, over very gravelly subsoils and substrata. The gravel is more or less cemented with lime at depths between 1½ and 3 feet, but is loose and porous below. The Avon soils are dark-brown soils on fans and terraces. They have compact subsoils and substrata.

The soils of the Millville and Mendon series are developed from more recently deposited alluvial fan materials over old lake clays. The Post and Taylorsville soils are developed on clayey old lake deposits. The Welby soils are developed on high stream terraces. All these soils are grayish brown or brownish gray in color, ranging from light to dark in shade, are slightly to distinctly limy in the topsoils, and have very limy, gray, rather fine-textured and more or less stratified subsoils.

The alluvial soils (Jordan, Logan, Onyx) are brown to dark gray in color, have little profile development, and are typically mellow and pervious throughout. Salts are concentrated in some of the lower lying, more poorly drained areas.

In southeastern Idaho and in northern Washington the Hyrum-Bingham-Avon soils are associated with soils of the Walla Walla and Ritzville areas, described on pages 1083 and 1090.

Use.—The land is largely under cultivation, either dry-farmed or irrigated. Some of the steeper, stonier, or coarser soils are used only for grazing. They have a rather low carrying capacity for livestock but much better than that of desert lands. Crops grown under irrigation include alfalfa, small grains, corn, sugar beets, tree fruits, and vegetables, all of which give good yields where sufficiently irrigated. The more gravelly soils require frequent irrigation. Wheat raising by dry-farming methods is fairly successful on the gravelly loam soils (Hyrum-Bingham) but less so on some of the finer textured soils such as the Taylorsville. Wetter areas of the alluvial soils are more or less salty and are useful only for pasture and wild hay. Better drained areas are very productive of vegetables, corn, small grains, and hay.

The chief needs of these soils are organic matter and nitrogen, which can best be supplied on the irrigated lands by growing alfalfa in the crop rotation and applying barnyard manure. Straw should be plowed under on the wheatlands, and contour plowing will help to minimize erosion. Superphosphate fertilizer greatly increases production on some of the lighter colored limier soils like the Taylorsville and Welby.

Keith Area

Geographic setting.—A large area in western Kansas, southwestern Nebraska, and northeastern Colorado has certain characteristic features of soil, climate, and vegetation. It is part of a high, smooth, treeless plain dissected at wide

intervals by comparatively narrow valleys. The elevation ranges from about 3,000 to 4,000 feet above sea level. The soils of the Keith series occupy the greater part of the smooth upland. This area resembles in many respects the Holdrege-Hall area to the east, and the two grade into each other with no perceptible line of demarcation. The grass cover here is somewhat sparse and soils are lighter colored.

Climate.—The average annual precipitation decreases across the area from east to west from 20 to 15 inches. The mean annual temperature is about 51° F. The average number of days free from killing frost ranges from 160 to 180.

Native vegetation.—Short grasses, of which grama and buffalo grass are dominant species.

Parent materials.—On the smooth plain is a silty material or loess deposited by wind; along the stream slopes, calcareous Tertiary rocks are exposed and contribute to the soil material.

Soils.—Keith silt loam occupies the greater part of the smooth uplands. The surface soil is dark grayish-brown mellow silt loam; the upper subsoil is dark grayish-brown and slightly heavier than the surface soil; and the lower subsoil is brown and, in places, has a weak development of claypan. Beneath this is the lime zone. The loose silty parent material usually occurs at a depth of 3 to 4 feet. Extensive areas of Keith very fine sand occur where very fine sand has been blown over the surface of silt loam areas. Sandy, calcareous soils, often containing fragments of sandstone or shale, occur on eroded areas along streams. Erosion is serious only on the more sloping cultivated areas.

Use.—These soils are productive of the general farm crops of the area insofar as the low rainfall will permit. Toward the northern part corn is an important crop. Farther south where the moisture supply is more uncertain grain sorghum is the important feed crop. Winter wheat is grown exclusively in a large part of the area and to some extent over the rest. The smooth surface favors the use of machinery and wheat is grown in many places on a large scale. In the western part of the area, average yields are low and a large percentage of the land is not cultivated.

Rosebud-Bridgeport Areas

Geographic setting.—These are areas of dark-brown soils in western Nebraska and adjacent parts of adjoining States. Elevation ranges from about 3,500 to 5,000 feet. These soils occupy flat to undulating tabular divides and eroded slopes which range from gentle to steep. Most of the smooth land with the exception of that part included in Indian reservations is in cultivation. The better areas of Rosebud soils in Nebraska are dotted with towns and have well-improved farms.

Climate.—Cool-temperate and semiarid. Average annual rainfall ranges from 15 to 20 inches. Summers are short and moderate to hot; winters are long and cold.

Native vegetation.—Short grasses, largely grama and buffalo grass.

Parent materials.—Light-colored calcareous sandstones and shales of Tertiary age.

Soils.—The dominant soils are fine sandy loams, loams, and silt loams of the Rosebud series. The surface soils, to a depth ranging from 8 to 14 inches, are dark grayish brown. The upper 1 or 2 inches is loose and mulchlike and the lower part has a fine mealy to crumblike structure. The upper layer of the subsoil is grayish brown and slightly heavier than the surface soil but is friable. This passes gradually into loose, light grayish-brown silt loam or very fine sandy loam. The partially weathered sandstone from which these soils are derived occurs at a depth ranging from 2 to 6 feet below the surface. Among the associated soils are the Tripp soils on terraces with a profile similar in its upper part to that of the Rosebud soils and the immature Bridgeport soils which have developed on terraces and colluvial slopes.

Use.—The smooth areas of the Rosebud loam and silt loam are used mainly for the production of wheat, corn, and oats. In most places these crops rank in acreage in the order named with no great difference in the areas of the three. Changes in the relative acreage of each may result from a fluctuation in prices or the repeated failure of any crop. Rye, barley, and potatoes are also grown. On the sandy soils corn and rye are the favored crops. The greater part of the nonarable land of these areas is included in pastures, especially for cattle. Wild hay is cut on the meadows and smooth uplands.

The present system of land use has been in effect for more than 25 years, and

notwithstanding the fact that dry seasons often decrease yields the average returns seem to have been sufficient to justify the continuance of the system.

Walla Walla Areas

Geographic setting.—The Walla Walla soils lie largely in the Columbia Plateau wheat section in northeastern Oregon and southeastern Washington, with smaller areas in southeastern Idaho. They occupy belts of treeless rolling uplands, roughly parallel to the thinly timbered mountains which rise above them. The areas commonly lie above the Ritzville soils and, in places, below the Palouse soils. The elevation ranges from 1,000 to 2,000 feet above sea level in Oregon and from 4,500 to 6,000 feet in Idaho. The region is thinly populated.

Climate.—Semiarid. Mean annual rainfall ranges from 14 to 18 inches. Summers, dry and moderate or hot. Winters rather long and cold.

Native vegetation.—Bunch grass (largely destroyed by cultivation).

Parent materials.—Loess (fine, floury, wind-borne material).

Soils.—Brown or grayish-brown to dark-brown, mellow, floury surface soils over soft, pervious, light-brown subsoils. Light-gray layer of lime concentration at average depth of about 5 feet. As developed in Idaho, the upper subsoil is heavier and tougher than the surface soil, yet not impervious to air, water, and roots. The soil erodes rather easily where unprotected.

Narrow bottom lands are occupied by darker-colored soils of the Onyx, Logan, Caldwell, and Adams series, which in places are poorly drained and more or less salty.

FIGURE 21.—A typical wheat farm on Walla Walla silt loam northeast of Walla Walla, Wash.

Use.—Nearly all under cultivation. Wheat is the only important crop. Land dry-farmed (fig. 21) in large units and summer-fallowed in alternate years. Yields moderate to large. Alfalfa, corn, and vegetables are grown on small areas of bottom lands where moisture conditions are favorable. Small irrigated areas highly productive of alfalfa, sugar beets, potatoes, apples, and prunes.

The Walla Walla soils are naturally very fertile, and partly for this reason they have been abused by some farmers. Straw and stubble are commonly burned, and as a result organic matter is being gradually depleted. This tends to make the soil erode more easily. Fall plowing enables the straw to rot but leaves the surface exposed to winter rains. Contour plowing and plowing in such a way as to leave the surface cloddy help to minimize loss of soil by erosion. Where plowing under straw depresses yields of the following crop, it may be possible to counteract this effect by use of nitrogen fertilizers, though this may not always be economically feasible.

Williams-Morton-Bainville Areas

Geographic setting.—The Williams, Morton, Bainville, and similar and associated soils occupy vast treeless reaches of the Great Plains in North Dakota, South Dakota, Montana, and Wyoming at elevations ranging from about 1,800 to 4,000 feet. The relief ranges from nearly level to hilly and broken. The greater part of the surface is made up of broad, undulating or gently rolling tabular divides broken by valleys with gentle to steep slopes.

Climate.—The average annual precipitation ranges over different parts of this

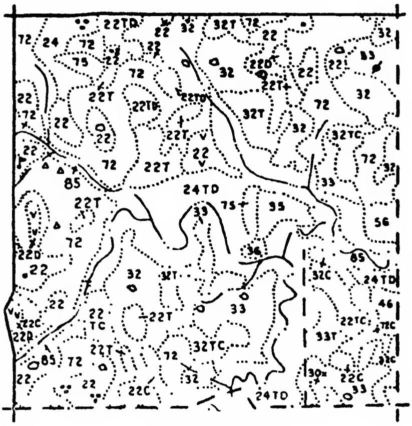
region from 14 to 18 inches. The mean annual temperature ranges from 40° to 44° F., but the climate is characterized by extremes of heat and cold. The average number of days free from killing frost ranges from 120 to 135.

Native vegetation.—Mixed short and tall grasses, including grama and associated species.

Parent materials.—Williams and Scobey soils are developed over calcareous glacial till. Morton and Bainville soils are developed over shales and sandstones. Alluvial and alluvial-fan outwash and terrace materials are extensive near the mountains in western Montana.

Soils.—The surface soils of the Williams series, ranging in thickness from 6 to 10 inches, are dark grayish brown but not so black as the soils of the Barnes series. The material is usually friable and in places gravelly or stony. The upper subsoil is brown or light brown; the lower subsoil, beginning at a depth of about 18 inches, is grayish yellow or almost white, owing to its high content of lime. In Montana, soils similar to the Williams but slightly lighter in color and with a thinner surface layer are called Scobey. Morton soils are similar in appearance to the Williams but are underlain by sandstones or shale. Thin soils developed over sandstones and shales in hilly areas have been classed with the Bainville series. Associated soils include the light-colored Patent and dark-colored Grail of the long gentle slopes. They exhibit less zonal development than the Williams and Morton soils (fig. 22). In parts of this region there are soils of minor importance over several kinds of parent materials, such as those in western Montana on outwash and terrace materials.

Use.—The cultivated land is devoted largely to the production of spring wheat. A number of factors determine the dominance of this crop: A climate too cold for winter wheat but favorable for spring wheat, mellow soils with a large percentage of organic matter, and a generally smooth surface and freedom from trees, brush, and stones, which favors large-scale farming with machinery. Flax, oats, and hay are among the other crops grown. On a relatively small area of irrigated land alfalfa is an important crop. Rough broken lands or excessively stony, gravelly, or shallow soils are used entirely for grazing. On farms that include both smooth and rough or stony land a system of mixed grain and livestock farming is practiced. This region, with its low rainfall, is near the western limit of successful dry farming. Agriculture to be permanent must be carefully adapted to the natural and economic conditions of the region.



LEGEND

72 Arnegard fine sandy loam
75 Arnegard silt loam.
22 Bainville loamy fine sand.
24 Bainville loam.
46 Gall silty clay loam.
32 Morton fine sandy loam.
33 Morton loam.
35 Morton clay loam.
36 Morton clay loam, solonized phase
56 Patent clay loam.
30x Pierce gravelly loam
85 Salton loam.
D Hilly phase.
C Rolling phase
T Stony phase.
°.° Gravelly area (1 to 2 acres)
Δ Shallow area (1 to 2 acres)
ø Solonized area (1 to 2 acres)
o Stony area (1 to 2 acres)
v Rock outcrop.

FIGURE 22.—A portion of the soil map of Morton County, N. Dak., illustrates the complex association of soils in parts of the Williams-Morton-Bainville area. The cultivated fields are discontinuous and irregular because of the distribution of the hilly and stony soil phases shown by the D and T symbols.

REDDISH CHESTNUT SOILS

The Reddish Chestnut soils are developed on the grassy plains from southern Kansas south through Oklahoma and Texas to the Gulf of Mexico. The climate is warm-temperate and semiarid or subhumid. The surface soils are typically dark reddish brown and friable, and the subsoils heavier and tougher, reddish brown to red in the upper part, and lighter or grayer in color and highly calcareous in the lower part. The vegetation is largely grasses, but in places there is a scattered growth of brush and small trees, and on some of the sandier areas a thick growth of small shin oak trees. These soils have relatively high inherent fertility, but the low rainfall and high rate of evaporation tend to limit crop growth. Important crops are cotton, grain sorghums, and wheat. Much of the land is used for grazing livestock.

Amarillo Areas

Geographic setting.—The Amarillo and associated soils occupy large areas in the southern part of the High Plains section in western Texas and extend into eastern New Mexico. Elevations range from 3,000 to 5,000 feet above sea level. The land is largely a treeless grassy plain, though much land is under cultivation in some sections.

Climate.—Warm-temperate and semiarid to subhumid. Summers long and rather hot; winters, rather short and moderate. Average annual rainfall 15 to 20 inches. Average length of frost-free season 175 to 200 days.

Native vegetation.—Coarse bunch grasses, largely bluestems. On loose sandy soils, a thick growth of very small shin oak trees.

Parent materials.—Plains marl and in places sandy Quaternary deposits.

Soils.—Amarillo soils have mostly red or reddish-brown sandy surface soils, though there are some areas of loam and clay loam. Subsoils are of red clay or sandy clay, passing at 2 to 5 feet into brown, buff, or yellow marl, containing an accumulation of soft carbonate of lime. In places sandy material composes the upper part of the subsoil. These soils absorb moisture quickly, have good water-holding capacity, are easily worked, and are productive soils on which crops withstand dry seasons more readily than on heavier clay loam soils. The sandier soils are subject to severe wind erosion and drift so badly in places that young crops are sometimes destroyed.

Use.—The proportion of the land cultivated ranges in different counties from 20 to 50 percent. Most of the rest is used for grazing livestock. Cotton is the most important crop in most places. Grain sorghums and corn are also common crops. Agriculture is fairly prosperous, though crop failures occur in very dry years. The land is farmed in large tracts. The average size of farms in counties where much land is in crops varies from 300 to 700 acres, but in counties where livestock ranching is most important, the average size is more than 1,000 acres.

Duval-Webb Areas

Geographic setting.—Duval, Webb, and associated soils occupy areas in southern Texas on the Rio Grande plain section of the Coastal Plain. The surface is generally smooth or undulating.

Climate.—Warm-temperate or subtropical and rather dry. Summers are long and hot; winters, short and mild. Average frost-free season ranges from 260 to 290 days. Rainfall is low, 20 to 30 inches, and often insufficient for growing crops.

Native vegetation.—Bunch grasses, largely bluestems, with some short grasses, including mesquite, buffalo grass, and gramas, and scattered small trees and shrubs, including mesquite and live oak.

Parent materials.—Beds of sandy and clay materials of the Coastal Plains formations.

Soils.—Duval and Webb are the principal soil series. The surface soils are mostly fine sandy loams or of other sandy textures. Duval soils have red or reddish-brown surface soils over red, very friable, sandy clay subsoils that grade below into more or less calcareous sandy parent materials. In many places the subsoil zone of carbonate of lime accumulation is not distinct, probably owing to rapid leaching. The Webb soils are not as red as the Duval and the subsoils are much tougher and denser.

Use.—Largely because of lack of moisture, a large part of the land is still used as range on cattle ranches. However, in some of the more easterly sections lands are successfully dry-farmed, and to the west some areas are farmed under irrigation from wells or streams. The soils are highly productive where moisture is sufficient, and they are suitable for growing cotton, corn, fruits, vegetables, sorgo, grain sorghums, and other feed crops. Watermelons, cantaloups, peanuts, sweetpotatoes, and other vine crops do well, and market gardening is important in localities where a good supply of underground water is obtained from wells.

Where properly used these soils afford a good standard of living.

Greensburg-Pullman-Richfield Areas

Geographic setting.—Greensburg, Pullman, Richfield, and associated soils occupy a number of areas on the High Plains of southern Kansas and in the Texas and Oklahoma Panhandles. The country ranges from nearly flat to undulating or gently rolling and in elevation from 2,000 to more than 3,000 feet above sea level.

Climate.—Warm-temperate and subhumid. Average annual rainfall ranges from 20 to 30 inches in different sections. Summers are rather long and hot and winters of moderate length and mild or rather cold. Average length of frost-free season ranges from 180 to 210 days in different localities.

Native vegetation.—Largely short grasses—buffalo grass and grama predominating.

Parent materials.—Deep beds of calcareous clays or marls of the Ogallala formation.

Soils.—Brown to very dark brown surface soils over dark-brown to reddish-brown subsoils and lighter colored or grayer highly calcareous substrata. Greensburg soils have very dark brown deep surface soils, chiefly silty clay loams and silt loams, which are mellow and have a basic reaction but are not calcareous, grading into heavy brown crumbly subsoils that are calcareous below about 4 feet but show no marked accumulation of calcium carbonate. Pullman soils have dark-brown surface soils over heavy dark-brown clay grading below through reddish-brown clay into calcareous yellowish-brown clay containing much chalky carbonate of lime below a depth of 4 or 5 feet. Richfield soils are as a rule on flat slightly depressed local areas. They are nearly black and have brown or gray clay subsoils.

Use.—These soils are highly productive when moisture is sufficient but in dry years yields are low. The greater part of the area is farmed. Wheat is the most important crop, occupying 80 to 90 percent of the cropland. The rest is used for barley, oats, grain sorghums, hay, and forage. In some of the southern counties of the Texas Panhandle, where the growing season is comparatively long, cotton is grown.

Farms range in average size from 350 to 600 acres in different counties, and large-scale dry farming is practiced. On the whole the country is fairly prosperous and supports a good standard of living, though occasional long droughts cause severe losses.

Miles-Vernon Areas

Geographic setting.—Miles, Vernon, Pratt, and associated soils occur in a number of large and many small areas in the Rolling Plains section of northern and northwestern Texas, western Oklahoma, and southern Kansas. They are reddish-brown or red soils, in many places occupying nearly all the land and in other places associated with dark-colored soils of the St. Paul-Abilene and Greensburg-Pullman-Richfield areas, usually occurring on steeper or more uneven land than the dark-colored soils. It is a country of large farms and livestock ranches, and is generally prosperous.

Climate.—Warm-temperate and subhumid. Average annual rainfall varies from 20 to 30 inches in various sections. Winters are moderate and rather short; summers, long and hot. Average length of frost-free season about 220 days in southern part and 190 days in northern.

Native vegetation.—Largely coarse grasses, such as bluestems, with grama and other short grasses. Very sandy soils have in places a growth of shin oak trees, generally only 2 or 3 feet high.

Parent materials.—"Red Beds" formation (clays and shales) and old sedimentary beds of sandy clay of Tertiary and Quaternary ages.

Soils.—The Miles, Weymouth, Tillman, Vernon, and Quinlan are the principal soils. The surface soils vary in color from red to reddish brown or grayish brown and range in texture from sand to clay. The subsoils are mostly red or reddish brown with light gray or white layers of lime carbonate accumulation in the lower part in most places. This subsoil lime accumulation is typical of the soils on the smoother land but is largely lacking in the soils of the steeper or more uneven lands, such as the Vernon and Quinlan soils. Miles soils have fairiy deep surface soils, usually rather sandy and mellow, over red sandy clay subsoils. In places they are associated with the Pratt soils, which commonly have rather dark grayish-brown surface soils. Weymouth and Tillman soils have rather thin reddish-brown surface soils over dull-red or reddish-brown crumbly subsoils. Vernon and Quinlan are thin, red immature soils. Vernon soils have heavy crumbly clay subsoils, and Quinlan very loose, light, sandy subsoils and substrata. Where unprotected, the sandier soils drift in the wind.

Use.—Miles soils, and the associated darker colored Pratt, are fairly productive; Weymouth and Tillman soils are moderate or rather low in productivity; and the Vernon are of low productive capacity.

A large proportion of the smoother lying areas of better soils is under cultivation to cotton, wheat, grain sorghums, and other feed crops. Cotton is the most

FIGURE 23. A view in the St. Paul-Abilene area in north-central Texas. This picture gives an idea of the broad plains upon which are situated the Reddish Chestnut soils. Note native vegetation in foreground.

important crop in the south, wheat in the north. These soils absorb moisture readily and hold it well, and crops grown on them sometimes withstand long periods of drought. Much of the thinner soils (largely Vernon and Quinlan) and associated rough broken land is used for livestock grazing. Lands naturally very subject to erosion should be kept in grass, or, if farmed, special measures should be used to control erosion.

St. Paul-Abilene Areas

Geographic setting.—St. Paul, Abilene, Hollister, and other associated dark-colored soils occur in the Rolling Plains section of north-central Texas and southwestern Oklahoma on the smoother lands associated with more uneven or sloping areas of red soils and rough broken land (fig. 23). Elevations range from 1,500 to 2,500 feet above sea level.

Climate.—Warm-temperate and subhumid. Average annual rainfall ranges from 20 to 30 inches in various sections. It is rather irregular and severe droughts sometimes occur. Winters are rather short and comparatively mild; summers, rather long and hot. Average winter temperatures range from 35° to 45° F. Frost-free season averages 200 to 220 days

Native vegetation.—Largely short grasses, with scattered mesquite and brush.

Parent materials.—Calcareous clays of the "Red Beds" and other formations.

Soils.—The typical dark-colored soils of these areas occur only on relatively smooth or flat land. The more important of these are the Abilene, St. Paul, Roscoe, Foard, and Hollister. The surface soils are generally of moderately

heavy texture (clay loams) and subsoils are mostly dark brown and heavy. Abilene soils have a very dark brown surface soil over very dark brown heavy upper subsoil and a layer of accumulated carbonate of lime in the lower subsoil. St. Paul soils are dark-colored soils with dark-brown subsoils somewhat more granular and less heavy than those of the Abilene. Roscoe soils have black surface soils over very dark heavy but crumbly subsoils. They occur in slight depressions and have slow drainage. Foard soils have very dark colored surface soils over dense dark-brown clay subsoils or claypans. Hollister soils are similar but the subsoils are not so dense and tough. Associated red and reddish-brown soils of areas smooth but not as flat are largely of Miles and Tillman series.

Closely associated with the dark soils but on the steeper and more uneven areas are thin red soils, largely of Vernon and similar series, rough broken land, and thin, light-colored soils such as those of the Potter series.

Use.—The dark-colored soils are highly productive in seasons of good rainfall, are well suited to the general farm crops of the region, and are largely under cultivation. The associated red soils, which are largely of sandy textures, are moderately productive and are farmed in conjunction with the dark-colored soils in many places. Where there is much rough broken land, red soils, and light-colored soils, the land is used largely for grazing. In the northern parts of these areas wheat is the principal crop, but farther south where the growing season is longer cotton is most important. Grain sorghums, sorgo, oats, corn, and other forage crops are also grown.

In spite of the good moisture-holding capacity of the dark soils, crops are occasionally curtailed or fail on account of drought. In general, however, farming is fairly successful. The crops grown are largely those that withstand drought well.

Zita-Pullman Areas

Geographic setting.—Zita, Pullman, and associated soils lie on the treeless High Plains of southwestern Kansas, western Oklahoma, northwestern Texas, and northwestern New Mexico, on high, smooth to gently rolling grassy areas, ranging from 3,000 to 5,000 feet above sea level with a gradual incline toward the west and north.

Climate.—Warm-temperate and semiarid. Winters are rather short and mild or moderate with average temperatures of 30° to 40° F.; summers rather long and hot. Annual rainfall ranges from about 15 to 22 inches, is irregular, and in some seasons is insufficient for crop production.

Native vegetation.—Short grasses, largely buffalo and grama grasses.

Parent materials.—Soft calcareous clay or plains marl of the Ogallala formation (Pliocene).

Soils.—Brown to dark-brown soils with dark-brown crumbly subsoils passing at 2 or 3 feet into calcareous, soft, crumbly yellow clay in which there is an accumulation of soft lime carbonate. Zita soils are on gently sloping lands and have brown surface soils over brown granular and calcareous subsoils. They are mostly silt loams and silty clay loams. Pullman soils (also described in connection with Greensburg-Pullman-Richfield areas) are on more level land, and have brown to dark-brown surface soils over heavy dark-brown clay subsoils, grading through a reddish-brown layer into light brown and then yellowish clay containing accumulated lime carbonate at a depth of 3 to 5 feet. They are mostly silty clay loams and silt loams.

Use.—These soils are fairly productive when moisture conditions are favorable. They are used largely for the production of wheat, not only on small farms but on very large areas where the smooth surface is favorable to the use of improved machinery. Grain sorghums and sorgo are minor crops. In some places, such as the Canadian River Valley, where there are many sandy areas and much rough, broken land, not more than 15 or 20 percent of the land is cultivated but is used mostly for grazing range livestock.

BROWN SOILS

The Brown soils cover a vast area in the western part of the Great Plains and smaller areas in the intermountain country of the far West. They exist under a temperate or cool semiarid climate and a native vegetation of short grasses, bunch grasses, and shrubs. The surface soils are brown, and the subsoils grade at depths ranging from 1 to 2 feet into light-gray or white calcareous layers. On the

Ritzville soils of eastern Oregon and Washington this lime layer is commonly 3 or 4 feet below the surface. Much of the land is used as livestock range, though large areas are dry-farmed, mostly to small grains and sorghums. Yields are low. Irrigated areas produce a wide variety of crops.

Baca-Prowers Area

Geographic setting.—Baca, Prowers, and associated soils occupy a section of the High Plains in southwestern Kansas, southeastern Colorado, northeastern New Mexico, the west tip of the Oklahoma Panhandle, and the northwestern corner of the Texas Panhandle. The surface is undulating to nearly flat and elevations range from 3,000 feet above sea level in the east to more than 6,000 feet above in the west. It is a country of livestock range and extensive dry farms. Farming is hazardous and wind erosion has been severe. The area contains a part of the so-called dust bowl.

Climate.—Continental and semiarid. Average annual rainfall ranges from 15 to 20 inches, but is irregular in occurrence, and serious droughts are rather frequent. Summers are somewhat long and hot; winters are moderate with average temperatures ranging from 30° to 40° F. Wind movement is high, especially in spring.

Native vegetation.—Rather thin growth of short grasses.

Parent materials.—Plains marl of the Ogallalla formation—yellowish-brown calcareous clay.

Soils.—Baca and Prowers soils are most extensive and there are a number of somewhat similar soils associated with them. These soils are mostly silt loams and silty clay loams, though there are also some sandy soils. The latter are especially subject to wind erosion. Baca soils are brown granular friable soils with brown crumbly clay subsoils underlain by grayish-brown chalky layers of accumulated carbonate of lime. Prowers soils have somewhat lighter colored gray or grayish-brown surface soils over subsoils of yellowish-brown, somewhat granular and friable calcareous clay or clay loam, with a chalky gray clay at 1 or 2 feet beneath the surface. Capulin soils (see Capulin-Tucumcari areas, below) are extensive in the western part of this area.

Use.—The proportion of land in crops ranges from 25 to 50 percent in various counties. Wheat is the most important crop, occupying 40 to 80 percent of the cropland. Grain sorghums, sorgo, and in places corn, are grown also under dry-farming methods. Alfalfa, sugar beets, and corn are important crops under irrigation.

Yields are good when moisture conditions are favorable, but during dry or excessively windy seasons crop failures are common, and the area may be considered climatically marginal for the production of most crops by dry farming. Much of the land is used for livestock grazing, and this is probably its best use in most places, though a certain amount of the land might well be used in most years to produce such feed crops as withstand dry conditions in order to supplement the range forage.

Capulin-Tucumcari Areas

Geographic setting.—Capulin, Tucumcari, and associated or similar soils occupy areas of high plains and plateaus in New Mexico and northeastern Arizona and extending into southern Utah and Colorado. The surface varies from smooth to rolling and in places is rather severely dissected and eroded. Elevation ranges from 4,000 to 7,000 feet or more above sea level. The country is thinly populated, treeless range land.

Climate.—Continental and arid or semiarid. Summers are rather long and hot; winters, moderate to cold. Average annual rainfall ranges from 10 to 18 inches, a large part of which falls in the summer.

Vegetation.—Rather thin growth of short grasses.

Parent materials.—"Red Beds" formation or other sedimentary beds of clays, shales, and sandstones, or outwash from such beds. Some basaltic material in places.

Soils.—Comparatively little is known of the soils of these areas, as they are almost entirely outside of areas covered by soil surveys. The soils range from light brown or grayish brown to brown or reddish brown in color, depending to a considerable extent on the color of the parent materials. The surface soils

are calcareous in many places and the subsoils are almost universally so. Capulin soils have brown, calcareous, friable surface soils, mostly loam and clay loam, over brown granular calcareous clay, grading below 12 or 15 inches into light-brown, calcareous, very granular clay and containing much chalky carbonate of lime below a depth of 2 or 2½ feet. In places the subsoil contains beds of large and small basalt fragments more or less cemented by carbonate of lime. Tucumcari soils have brown to reddish-brown granular surface soils that are not calcareous. The subsoils are reddish-brown calcareous clay with some white lumps or nodules of accumulated carbonate of lime at a depth of 2 or 3 feet. In places Vernon, Reagan, Amarillo, and Winslow soils are included in these areas.

Use.—The land is nearly all used for livestock grazing, being mainly in either large ranches or public ranges. The climate is too dry to allow consistently successful dry farming. Many of the smoother areas would doubtless be very productive if they could be supplied with irrigation water. Some small included areas of irrigated bottom lands (Gila soils) are highly productive and are used largely for production of alfalfa, grain sorghums, corn, vegetables, and fruits.

Joplin Areas

Geographic setting.—Joplin and associated soils are in Montana, Wyoming, and northern Colorado on the western part of the northern Great Plains, a treeless semiarid region, consisting of a succession of smooth tabular divides with intervening valleys of rolling or rough land. Occasional areas are so sharply dissected as to approach a badland topography. Elevation ranges from about 2,000 to 7,000 feet.

Climate.—The mean annual precipitation ranges from 10 to 18 inches. Over the greater part of the region the moisture supply is too low for successful dry farming.

Native vegetation.—Short grasses, grama and buffalo grass predominating.

Parent materials.—Glacial drift in the northern part; shales and sandstones in the central and southern parts.

Soils.—The soils vary considerably, depending on the parent material and the relief. The surface layer of the Joplin soils to a depth of 7 to 10 inches is grayish brown or gray. In unplowed land the upper 1 or 2 inches is usually loose and mulchlike. The subsoil is grayish brown or brown. At a depth of 12 to 16 inches the soil is underlain by light-gray, very calcareous material. This in turn is underlain at 24 to 30 inches by the parent material, which is a thin glacial drift. In southern Montana and eastern Wyoming light-colored soils with profiles similar to those of the Joplin series are developed over sandstones and shales.

Use.—The greater part of this area is used as livestock range, though extensive areas are dry-farmed to wheat, chiefly spring wheat. Barley and hay crops are also grown. Alfalfa, potatoes, and sugar beets are grown on irrigated areas.

Dry farming has been carried on with varying results. A number of favorable seasons are succeeded by years of failure. A large part of the area is to be regarded as marginal. Irrigation, mainly on terraces and alluvial bottom lands, has been highly successful.

A considerable part of the upland soils has been damaged by wind erosion. Protection of this land from wind erosion presents the principal problem in soil conservation.

Ritzville Areas

Geographic setting.—The Ritzville soils occur on rolling uplands in western intermountain valleys and plateaus. The larger areas are in the Columbia Plateau wheat section of Washington and Oregon, and narrower belts are in southeastern Idaho and northern Utah. The elevation ranges from 500 to 1,500 feet in Washington and Oregon and from 4,000 to 5,000 feet in Idaho and Utah. The country is thinly populated.

Climate.—Semiarid. Rainfall 10 to 15 inches. Summers dry and rather hot, winters moderate or cold.

Native vegetation.—Bunch grass, with scattering of sagebrush and other shrubs.

Parent materials.—Loess (fine, floury, wind-borne material). In places there is a small amount of material residual from basalt or other rocks. Small areas of alluvium included.

Soils.—Surface soils are very mellow, light grayish-brown to brown fine sandy loams to silt loams. Subsoils are open and pervious and lighter colored than the surface. At depths of 3 to 6 feet lies a light-gray layer of lime concentration, which in most places is only slightly more compact than the material above.

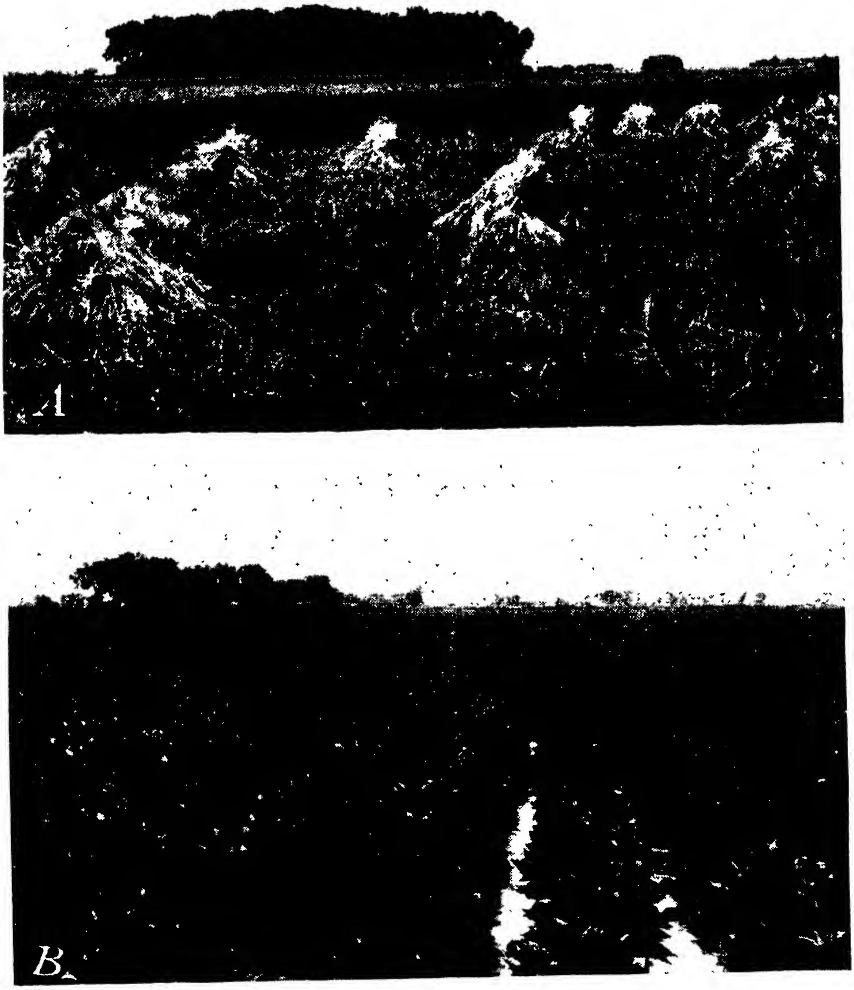


FIGURE 24.—Weld fine sandy loam is a productive soil under irrigation: *A*, Barley in shocks, oats standing; *B*, beans grown for seed near Lucerne, Colo.

Floury loess extends to great depth in most places. In places in Idaho the subsoil is somewhat heavier and more compact but is still easily pervious to water and roots. The sandier soils have a tendency to blow, especially if plowed, and wind erosion is severe in places. Small areas of alluvial soils are somewhat darker or browner, and are mellow and pervious throughout.

Use.—The greater part of the land is dry-farmed in large tracts to wheat, with summer-fallow in alternate years. Yields are moderate or low. Rather large areas, especially of the sandier types, are either in virgin condition, affording some grazing, or have been farmed and abandoned and are grown up to Russian-thistle and mustard. Range carrying capacity is rather low but better than that of the Desert soils. Some small areas are under irrigation and are very productive of alfalfa, small grains, tree fruits, corn, sugar beets, potatoes, and vegetables.

The sandier and steeper areas should not be farmed but used for range. In some cases blowing may be lessened by disking stubble land instead of plowing.

Weld-Fort Collin's Areas

Geographic setting.—Areas of brown soils cover the western side of the Great Plains to the foothills of the Rocky Mountains at elevations ranging from about 4,000 to 5,500 feet. In Colorado and the extreme western part of Kansas, the important soils are those of the Weld, Fort Collins, and associated series. Detailed surveys have been made over only a small part of the region and our knowledge of the soils of much of it is limited. The country is mostly too dry for dry farming, and intensive agriculture is confined to relatively small irrigated areas. The upland consists of smooth, level to undulating plains broken by occasional stream valleys with gentle to steep slopes. Near the mountains are numerous terraces and outwash fans with a nearly level surface, well suited to irrigation. The irrigated land is characterized by small well-improved farms and prosperous towns and villages.

Climate.—The average annual precipitation is less than 15 inches and the mean annual temperature about 48° F. The region is characterized by strong winds and a high rate of evaporation.

Vegetation.—Short grasses; grama and buffalo grass are the dominant species.

Parent materials.—The Weld and associated soils are developed on unconsolidated material, the greater part of which has been deposited by wind. The Fort Collins and associated soils along the foothills of the Rocky Mountains have developed on the material of alluvial fans and terraces, consisting of debris brought down from the Rocky Mountains.

Soils.—The surface layer of the Weld soils is a loose light grayish-brown platy mulch with a thickness of 1 to 2 inches. This is underlain to a depth of 9 inches by brown, moderately heavy silty clay loam or clay loam with a pronounced prismatic breakage. Below a depth of 12 inches is a light-brown or olive-brown highly calcareous silty layer which rests on light grayish-yellow wind-laid material consisting largely of limy silt. The soils of the Fort Collins series occupy most of the terraces. Their profiles rather closely resemble those of the Weld soils, but contain some gravel, especially in the lower part. These soils hold water fairly well under irrigation. Gilcrest soils on the gravelly terraces and the Greeley soils on sandy benches have loose porous subsoils and require much water. The Terry and Larimer soils of the upland are underlain by shale and gravelly sandstones, respectively.

Use.—The important crops of the irrigated lands are sugar beets, alfalfa, and small grains (fig. 24). Corn, truck crops, and small fruits are also grown. Dairying and feeding of sheep and cattle are important enterprises. A part of the Weld soils is used under dry farming for the production of wheat, other small grains, and corn. The conservation of soil moisture is the most important problem of the farmer who practices dry farming. Wind erosion is a serious menace in the dry-farming areas, especially in the southeastern part. A large part of this region, including the rolling land, is used for grazing cattle and sheep.

REDDISH BROWN SOILS

The Reddish Brown soils are in semiarid areas of the Southwest from western Texas to southern Arizona. They exist under a warm-temperate climate with hot summers, and support a rather thin short-grass or bunch-grass vegetation with scattered shrubs and small trees, especially mesquite. The surface soils are typically reddish brown to red in color and of mellow consistency; the upper subsoils are red or reddish brown, heavy and rather tough; and the lower subsoils are pink or nearly white and very limy. These soils have high inherent fertility but because of the arid climate they are largely unsuited to dry farming. Most

of the land is in livestock ranches or public range, though some rather small areas are irrigated and highly productive. Areas of darker, grayer soils as the Maverick and Uvalde—probably Rendzinas—are associated with the Reddish Brown soils.

Maverick-Uvalde Areas

Geographic setting.—The Maverick, Uvalde, and associated soils lie on the western part of the Rio Grande plain of southern Texas, an undulating to gently rolling plain rising from near sea level on the Rio Grande to several hundred feet above sea level at the north. A belt of rough broken land several miles wide borders the Rio Grande Valley. Much of the country is range, though there are considerable areas of highly developed irrigated land in certain sections.

Climate.—Warm-temperate or semitropical and semiarid. Summers are long and hot; winters, short and mild. Frost-free season averages 280 to 300 days. Average annual rainfall ranges from 15 to 20 inches. It is of rather irregular occurrence and often not sufficient for crop production.

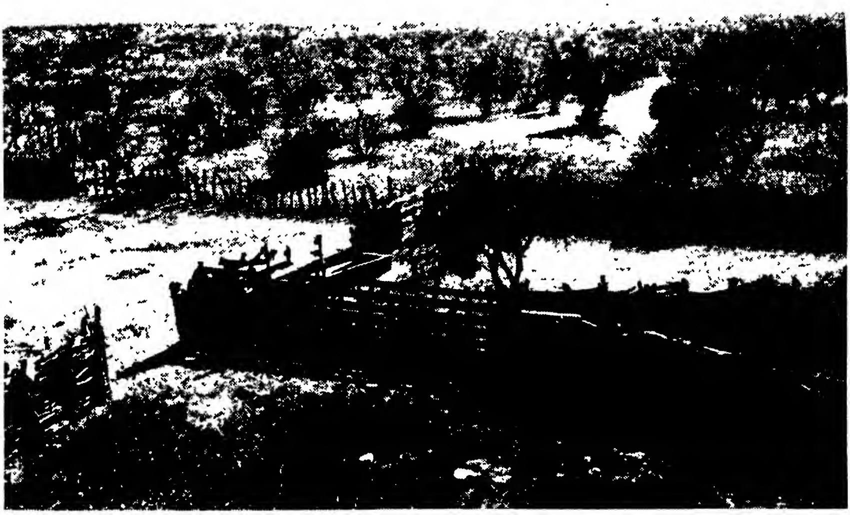


FIGURE 25.—Native vegetation on smooth-lying Maverick clay.

Vegetation.—Short grasses, mainly curly mesquite and grama with some buffalo grass; many shrubs and small trees of scattered open growth in places, especially on the smoother land (fig. 25).

Parent materials.—Sandy clays and clays of the Coastal Plain formations, many of which are calcareous.

Soils.—The more important soils are of the Maverick, Uvalde, Reagan, Crystal, Brennan, and Hidalgo series. They are rather light-colored soils over light-gray or grayish-brown highly calcareous subsoils.

Maverick soils lie on undulating or gently sloping land and are rather thin, immaturely developed soils. They have brown or grayish-brown calcareous surface soils, ranging from fine sandy loam to clay. The upper subsoils are brown or grayish-brown rather heavy clay, and the lower subsoils light-gray or nearly white very limy clay. They are fairly productive where not too thin. Uvalde soils lie on very smooth land. They have medium to dark gray deep surface soils over light-gray or grayish-brown fairly friable subsoils. Reagan soils (Reagan-Springer areas, p. 1093) are rather thin soils with grayish-brown surface soils over gray or grayish-brown friable clay subsoils. They are not

extensive in this section. Brennan soils are light-colored sandy soils, not calcareous in the surface soil and upper subsoil. Crystal soils have brown or reddish-brown rather sandy surface layers over subsoils of reddish-brown soft crumbly clay which grades below 2 feet into friable light grayish-brown calcareous clay containing chalky material. They are moderately productive. Hidalgo soils have grayish-brown calcareous surface soils, mostly fine sandy loam, over brown or light grayish-brown crumbly subsoils.

Use.—Most of the soils of this section that lie on smooth land are highly productive when moisture conditions are favorable, but owing to low and irregular rainfall, dry farming is seldom successful. Much of the land is irrigated from streams and wells. Cotton and feed crops are the principal crops where general farming is practiced. In the southern section, along the Rio Grande, vegetables and citrus fruits are produced, though these are raised largely on the associated alluvial soils. In the northern section, occupying part of the so-called winter garden district, considerable areas are irrigated from wells and from a few streams, and large quantities of winter-grown vegetables are raised and shipped to northern markets. The chief products are spinach, onions, and peppers, and various other vegetables are raised in smaller quantities. Unirrigated areas are used as range for livestock.

Reagan-Springer Areas

Geographic setting.—Reagan, Springer, Lea, and associated soils are on the High Plains in eastern New Mexico and western Texas. This section is largely a smooth, nearly flat to gently undulating plain, rising gradually from about 3,000 feet in the south to 5,000 feet in the north. It is a thinly populated range country.

Climate.—Continental and semiarid. Winters are short and mild or moderate; summers, long and hot. Average annual rainfall ranges from 12 to 20 inches.

Native vegetation.—Short grasses, largely buffalo grass and grama on the heavier soils and bluestems and other coarse grasses on the sandy soils. Shrubby growth of shin oak is abundant on some of the very loose sandy soils, and small mesquite trees are thinly scattered over the heavier soils in the southern part of the area.

Parent materials.—Highly calcareous clay and sandy clay, old plains outwash of the Tertiary and Quaternary periods.

Soils.—Reagan soils have light-brown or grayish-brown calcareous surface soils, mostly of silt loam and clay loam, grading into crumbly granular calcareous brown or yellowish-brown clay subsoils, and at a depth of 1 to 3 feet into light yellowish or grayish-brown soft calcareous clay containing lumps and nodules of soft carbonate of lime. Springer soils have light-brown or brown mostly sandy surface soils over reddish-brown subsoils with an accumulation of carbonate of lime at a depth of 2 or 3 feet below the surface, or deeper in very sandy soils. Lea soils, lying in long, narrow, slightly depressed areas, have dark surface soils over brown subsoils, passing below into gray chalky clay beds. All these soils overlie a hard, limestonelike caliche, usually within 6 feet of the surface. In places this caliche comes very close to the surface or outcrops and the thin soil contains many hard fragments. Such areas are in places locally referred to as scabland.

Use.—The land is mostly in large ranches on which large numbers of cattle and sheep are grazed. The cultivated area is small, ranging from 5 to 10 percent of the total land area in different counties. Although large areas are naturally productive when moisture is sufficient, rainfall is too small and too irregular to insure crop production. Dry farming is very uncertain, but some small areas irrigated from wells are very productive (fig. 26). The principal crops are feed crops, mainly sorghums, corn, and cotton.

White House-Tumacacori Areas

Geographic setting.—The White House and associated soils lie on long alluvial-fan slopes descending from the rugged, stony, sparsely timbered mountain ranges of southeastern Arizona and southwestern New Mexico. These fans, lying at elevations of 3,000 to 6,000 feet, merge at the lower altitudes with the shrubby desert plains. There are very few inhabitants.

Climate.—Semiarid. Rainfall 10 to 20 inches, falling largely in two periods—in the summer as torrential rains and in winter as gentle showers. Summers long and hot. Winters short, mild, and sunny.

Native vegetation.—Semidesert grassland and shrub. Grasses include several species of grama, *Aristida* spp., *Muhlenbergia* spp., tanglehead, curly mesquite, and *Triodia* spp. Shrubs are mostly mesquite and burroweed (fig. 27).

Parent materials.—Largely alluvial-fan deposits with small included areas of materials residual from bedrock. Granite, syenite, and other acid igneous rocks most common. Some sedimentary and metamorphic rocks in places.

Soils.—The White House soils have reddish-brown or brownish-red mellow gritty surface soils, in many places gravelly or stony and with a thin concentration or "pavement" of gravel on the surface. Subsoils are red, heavy, and compact. Lime accumulation occurs in the subsoil at depths between 3 and 6 feet. The Comoro and Tumacacori soils are developed from more freshly deposited alluvial-fan materials, are entirely leached of lime, coarse and pervious throughout, and of darker or browner color. A few areas of Coronado soils on the lower foot-

FIGURE 26.—Small irrigated areas in the valleys of western Texas are highly productive.

hills are dark-brown shallow soils over bedrock. Small areas of Pinal soils with massive lime hardpan are included in the lower parts of these areas.

Use.—Most of the land is of value only for grazing. It has only a fair carrying capacity for livestock, but much better than that of adjoining desert lands. Dry farming has been attempted on some small areas but has not been very successful, probably because of unfavorable climate.

Control of grazing is desirable in these areas to prevent killing out of desirable range grasses and to minimize erosion.

NONCALCIC BROWN (SHANTUNG BROWN) SOILS

These soils are developed under a warm semiarid or subhumid climate with cool moist winters and rather hot dry summers. They lie in the mountains, hills, or intermountain valleys of southern and central California and central Arizona. They are either under a chaparral (brush) and thin forest cover or are grasslands with a few scattered trees. The surface soils are brown, reddish-brown, or red, mellow or somewhat compact; subsoils are heavier, tougher, and redder, and commonly leached of lime carbonate but about neutral or slightly alkaline in reaction. The land of the hills and mountains is useful mainly for livestock range and for water conservation and recreational purposes. Much of the valley land is under irrigation and highly productive of citrus and deciduous fruits and other intensive crops. Some areas are dry-farmed to wheat or barley for grain or hay.

Placentia-Ramona Areas

Geographic setting.—The Placentia, Ramona, and associated soils occur mainly in central and southern California. The areas in central California are small and are not shown on the map. These soils occupy sloping valley plains and alluvial-fan and old stream-terrace surfaces or remnants which are frequently well elevated above the more recent alluvial soils of the Hanford and Cajon series of the valley floor. Drainage is well developed and the steeper slopes are subject to erosion and frequently incised by stream channels and gullies. The areas range in elevation from less than 100 to 2,500 feet.

Climate.—Subhumid to semiarid; average rainfall ranges from 10 to 20 inches, falling mainly during the winter months. Summers are hot except where modified by fogs and coastal influence. Long growing season of 210 to 240 days, with

FIGURE 27.—Grassland vegetation on White House gravelly sandy loam occupying elevated alluvial-fan slope of the Santa Rita Experimental Range near Tucson, Ariz. Foothills of Santa Rita Mountains in distance.

some areas included in which winter frosts are infrequent. Low relative humidity and high percentage of sunshine.

Native vegetation.—Tall bunch grasses, with arid-shrub vegetation in the more elevated areas of Placentia soils.

Parent materials.—Old alluvial-fan and valley materials derived from granitic rocks.

Soils.—Brown surface soils with reddish-brown, compact, moderately heavy textured subsoils in the Ramona; and more pronounced reddish-brown to dull-red surface soils with heavy dull-red colloidal prismatic subsoils in the Placentia series. Surface and subsoils leached of lime but neutral in reaction. Surface soils are dominantly of sandy loam to loam and of gritty texture, fairly friable under cultivation and of good water-holding capacity.

Use.—Agricultural development and use of these soils present wide contrasts depending upon the water supply for irrigation and local climatic variations. In irrigated sections that are comparatively free from frost they are the principal citrus-producing soils. Other areas are used for truck crops, deciduous fruits, and berries. They are thickly and attractively settled and intensively cultivated.

Nonirrigated areas are utilized under more extensive systems of management for grain, hay, and beans, and where topography and rainfall are less suitable, for grazing of sheep and cattle.

Vista-Holland-Sierra Areas

Geographic setting.—The Vista, Fallbrook, Holland, Sierra, and associated soils occupy the lower Sierra Nevada foothill belt and upland and mountain areas in southern California and in central and southern Arizona. Elevations in California range from about 300 feet at the lower margin of the Sierra foothills to about 5,000 feet in the southern California mountain ranges, and in Arizona from 2,000 to 6,000 feet. The foothill areas are of smooth and gentle to moderate slope but with frequent rock outcrop and incised ravines and river valleys. The higher mountain areas are steep and stony. The Sierra foothill areas are agriculturally most important and are associated with the Aiken soils at the higher and with the San Joaquin and Redding soils at the lower elevations.

Climate.—Subhumid, with mean annual rainfall of 15 to 30 inches and long, dry summers with high percentage of sunshine. The lower areas have little or no

FIGURE 28.—Irrigated deciduous fruit district in the lower Sierra Nevada foothills in California. The lower foreground is occupied by soils of the Holland and Sierra series, the more elevated distant slopes by the Aiken soils.

snowfall with long growing season. The more elevated mountain areas have rather severe winters and occasional heavy snow.

Native vegetation.—Digger pine and chaparral consisting of manzanita and ceanothus, with a few live oaks and other broad-leaved trees and some juniper and ponderosa pine at the higher elevations.

Parent materials.—Granitic rocks including gneiss, granodiorite, and similar rocks.

Soils.—These soils are rich-brown to reddish-brown gritty and granular sandy loam and loam surface soils with reddish-brown to dull-red compact subsoils of blocky to prismatic structure. They are feebly to mildly acid in the Sierra and Holland soils and feebly or mildly alkaline in the Vista and Fallbrook, but usually without free lime. Bedrock is at depths of a few inches to several feet, depending on variable depth of weathering and erosion. Associated alluvial stream valley and alluvial-fan soils, mainly of the Cajon and Hanford series, are of high agricultural value where irrigated.

Use.—Irrigated foothill areas are intensively utilized and highly valuable for

early deciduous fruits, mainly plums, peaches, cherries, and pears, and for citrus fruits in the more frost-free localities (fig. 28). The land is somewhat subject to erosion, and careful cultivation and fertilization are essential. The more elevated areas are utilized mainly for pasture. Expansion of agriculture is dependent upon the development of water supply for irrigation.

SIEROZEM AND DESERT SOILS

Sierozem and Desert soils occupy vast reaches of desert or semidesert in the western intermountain region. The climate is arid and warm to cool-temperate. The vegetation is of desert shrubs, principally sagebrush and shadscale. The surface soils are typically light grayish-brown or gray in color and low in organic matter. Subsoils are slightly lighter in color and very limy. These soils are very little leached, are rich in mineral plant nutrients, and in places contain very high concentrations of soluble salts. Most of the land is useful only for livestock range with low carrying capacity. Under irrigation these soils are highly productive of a wide variety of crops, including alfalfa, potatoes, small grains, vegetables, and fruits. Some areas are too salty or too alkaline to produce crops.

Navajo-Chipeta Areas

Geographic setting.—The Navajo, Chipeta, and associated soils lie on high desert plateaus and mesas of the intermountain West, in northern Arizona, eastern Utah, western Colorado, and Wyoming, at altitudes of 4,000 to 7,000 feet. The plateaus are in places cut by deep box canyons or walled in by high mountains.

Climate.—Arid. Rainfall 5 to 10 inches. Summers moderate or hot, winters cold but sunny.

Native vegetation.—Desert shrub. Shadscale, saltbush, rabbitbrush, and sagebrush. Thin growth of bunch grass in places. Greasewood and seepweed on salty land.

Parent materials.—Largely sandstones, shales, and limestones of infinite variety of color, and alluvial outwash from these formations. Some basalt or other igneous and metamorphic rocks present in places.

Soils.—Soil color is determined largely by color of parent materials, varying from gray to red with many intervening shades of drab, brown, yellow, and pink; little organic matter in the soil. Soils are normally highly calcareous in both surface soils and subsoils, with distinct concentration of lime and often of gypsum in the subsoils, in places forming a cemented hardpan. Soluble salts present in moderate to high concentrations in many places. These soils are naturally subject to rapid erosion.

Use.—The larger part of these areas is desert, useful only as range for livestock, principally sheep, and has a very low carrying capacity. The water supply for irrigation is limited and there are only a few comparatively small irrigation developments. Where the soil is deep, well drained, and free from excess of salts, fairly good crops of alfalfa, wheat, barley, and sugar beets are grown under irrigation. The alluvial soils such as the Billings constitute most of the successfully cultivated lands. The shallow soils of the uplands are relatively unproductive. Around Grand Junction, Colo., tree fruits are extensively grown on Billings, Mesa, and Fruita soils.

Irrigation water should be handled carefully, as these soils wash badly. Organic matter and nitrogen should be incorporated in the soil in the form of manure and by growing alfalfa in the crop rotation. Superphosphate fertilizer produces large increases in yields of alfalfa and sugar beets. Seepage and concentration of salts ("alkali") are common on irrigated lands. Artificial drainage and leaching is essential if affected lands are to be cultivated. Control of grazing and reestablishment of natural vegetation would tend to reduce destructive erosion on the range.

Panoche Area

Geographic setting.—The Panoche and associated Lost Hills soils occupy a belt on the southern west side of the great central valley in California. They occur at elevations of 200 to 1,000 feet above sea level on gently to steeply sloping

alluvial fans. The surface is smooth, except in the lighter textured types which in places are wind-blown and hummocky, but it is frequently cut by deep narrow channels of intermittent streams. The lower areas include poorly drained flats in which salts have accumulated. The areas are sparsely populated except for scattering sheep and cattle ranches and occasional towns and settlements associated with extensive development of oil and gas fields, mainly on associated soils of the Kettleman series.

Climate.—Arid; mean annual rainfall of 3 to 12 inches, with long rainless hot summers, little fog, low relative humidity, brisk wind movement, and frequent winter frost.

Native vegetation.—Bunch grasses and desert shrubs and annuals, including species of *Atriplex*, greasewood, pickleweed, with occasional Indian-tobacco and cottonwood along streamways.

Parent materials.—Alluvial outwash from adjacent shale, sandstone, and conglomerate soil materials of the Kettleman and associated soils.

Soils.—Light brownish-gray highly calcareous surface soils, mostly fine sandy loams and loams over lighter gray or yellowish-gray subsoils of high lime content. The Panoche soils are recent alluvial accumulations with little or no profile development and with disseminated lime. The Lost Hills soils represent a youthful but older stage in profile development, with compact subsoil and accumulated lime in the form of mottlings, nodules, and more or less cemented caliche layers.

Use.—Mainly without water supply for irrigation, these lands are used chiefly for grazing. Small irrigated areas are used for grains and sugar beets with uncertain results, depending upon water supply. The soils would be subject to severe erosion under heavier rainfall or careless irrigation. They furnish early spring grazing for sheep and cattle but are otherwise of low economic value.

Portneuf-Sagemoor Areas

Geographic setting.—The Portneuf, Sagemoor, Wheeler, and associated soils lie on extensive intermountain desert plains and plateaus of the Great Basin and Snake and Columbia River Basins, in Nevada, Utah, Idaho, Oregon, and Washington. Elevations range from 200 to 6,000 feet.

Climate.—Arid. Rainfall 5 to 12 inches, mostly in winter. Summers rather hot, winters moderate or cold. Average length of frost-free season ranges from about 100 to 180 days.

Native vegetation.—Desert shrub, including sagebrush, shadscale, rabbitbrush. Greasewood, saltbush, seepweed, and pickleweed on saline areas. Thin growth of short-lived annual grasses and herbs in spring.

Parent materials.—Largest areas, especially in the Great Basin, overlie old lake sediments (Sagemoor, Woodrow soils). Extensive areas of loess in Idaho and Washington (Portneuf and Wheeler soils). Alluvial-fan outwash present around bases of mountains. Materials from great variety of rocks—limestone and basalt most common. Sandy alluvial terraces occur along Snake and Columbia Rivers.

Soils.—Most of this area has never been mapped by the Soil Survey Division and the characteristics of the soils are intimately known only in a few localities where detailed soil surveys have been made. Surface soils range from light gray to brown and from not calcareous to distinctly so. Subsoils are typically light gray or nearly white, very limy and compact. The Sagemoor soils are less leached and more typical Desert soils than the Portneuf, which are similar to the Brown soils. The sandier soils of the terraces such as the Quincy, Ephrata, Rupert, and Winchester are very loose and leachy and in places have no lime carbonate in the profile. The alluvial soils, which occupy narrow bottom lands, vary in color from light brown to dark grayish brown, are mellow and free from lime concentration in the subsoils. In some of the lower lying poorly drained areas soluble salts are present in excessive quantities.

Use.—The larger part of these areas serves only as range for livestock, especially sheep, and its carrying capacity is low. There are a number of large irrigation developments, especially on the Portneuf soils, which are highly productive under adequate irrigation (fig. 29). Principal crops: Alfalfa for hay and seed, wheat, potatoes, beans, sugar beets, clover seed, and tree fruits, including apples, prunes, pears, peaches, and sweet cherries. Minor crops: Corn, barley, field

peas, and vegetables. Sandy and gravelly soils are irrigated to some extent, but they require large quantities of water. They are best adapted to alfalfa, tree fruits, corn, and melons. On some of the wet alluvial soils wild hay is commonly grown. Feeding range livestock is important on many ranches and farms.

These soils are typically low in nitrogen and organic matter, which may be supplied by growing alfalfa in the crop rotation and plowing under crop residues and manure. Crop yields on many of the soils are greatly increased by the use of superphosphate.

RED DESERT SOILS

The Red Desert soils are in the hot, arid Southwest, from Texas to southeastern California. They are light pinkish-gray, reddish-brown, or red soils with reddish-brown or red heavier and more compact upper subsoils and pink or white very limy lower subsoils. They are only slightly leached and are rich in lime and mineral plant nutrients. When irrigated they are highly productive of a wide

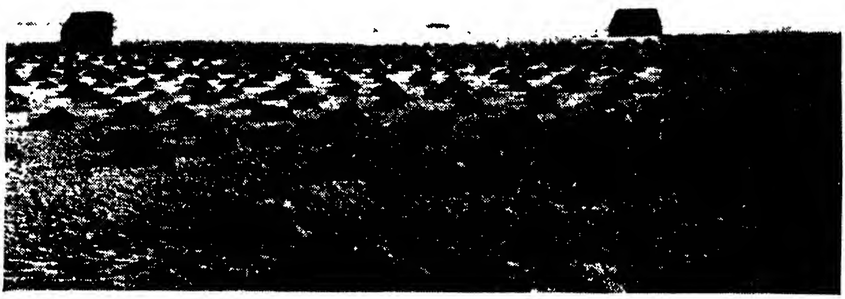


FIGURE 29.—Heavy yield of alfalfa hay on Portneuf silt loam near Twin Falls, Idaho.

variety of crops. Only one area—the Mohave-Reeves-Anthony—is shown on the soil map of the United States.

Mohave-Reeves-Anthony Areas

Geographic setting.—The Mohave, Reeves, Anthony, and associated soils are situated in the southwestern brushy, cactus-studded deserts, from western Texas to California. They lie on alluvial fans, stream terraces, and plains, interrupted here and there by low, barren, stony mountain ridges. A number of beautiful irrigated valleys with thriving cities are situated in these areas.

Climate.—Hot-arid. Rainfall 3 to 12 inches, mostly as gentle winter rains and torrential midsummer thunderstorms. Summers long and very hot; winters short, mild, and sunny.

Vegetation.—Desert shrub, mostly creosote bush. Cacti (including giant cactus), mesquite, paloverde, ironwood, bur-sage, shadscale, and *Gutierrezia* spp. are prominent in places (fig. 30). Small short-lived annual herbs and grasses spring up following rainy seasons.

Parent materials.—Largely alluvial outwash from great variety of rocks composing the mountains, laid as stony, gravelly, or gritty deposits on fans or as finer sediments on stream terraces and alluvial flats. Some areas are of residual materials from granite, basalt, and sedimentary rocks.

Soils.—Surface soils vary from light pinkish gray to reddish brown or red, and

are either distinctly limy or somewhat leached to a depth of a few inches. Subsoils are very highly calcareous and more or less cemented by lime, iron, or silica, and in places contain concentrations of gypsum (as in Reeves soils). In large areas the surface soils are light reddish brown, there is an upper subsoil (B_1) layer of reddish-brown or red, heavy, tough material containing much clay or colloidal matter. This is typical of the Mohave, Tucson, and Verhalen soils. The Anthony soils are similar to the Mohave but have less profile development and compaction. The Laveen and Reeves have light grayish-brown to pinkish-brown surface soils over gray or nearly white subsoils very high in lime. The Pinal and Las Vegas soils have very hard, extremely developed hardpans resembling concrete (fig. 31). The alluvial soils such as the Gila, Pima, Cajon, Pecos, Arno, Patrole, Yoyah, and Balmorhea, are typically mellow and pervious throughout. Some

FIGURE 30.—Typical vegetation on Red Desert soils. Cholla cactus in center, barrel cactus in left foreground, and small giant cactus in right background.

small areas, especially on the alluvial flats, are imperfectly drained and contain large quantities of soluble salts ("alkali").

Use.—These areas are used mostly as range land, furnishing very scant grazing or browse for livestock. They can be successfully farmed only under irrigation, and limited water supply prevents cultivation of the greater part. Chief crops are alfalfa, cotton, and grain sorghums; some barley, wheat, and corn are grown. At lower elevations, where winters are very mild, market-garden crops, principally lettuce and cantaloups, are grown, and in a few of the more frost-free areas citrus fruits, dates, and early table grapes are produced.

The chief needs of these soils, aside from irrigation, are nitrogen, organic matter, and phosphorus. The first two may be most easily supplied by growing alfalfa in the rotation and by use of barnyard and green manures. Phosphorus is best supplied in superphosphate fertilizer.

PLANOSOLS

The distinguishing feature of Planosol soils is the accumulation of a well-defined layer of clay or cemented material at varying depths below the surface. This development has taken place on nearly level areas where drainage is more or less restricted. These soils occur on flat upland areas in the Middle West and in parts of Texas and California. Since they cover such a wide area, they are necessarily developed from many kinds of parent material and have been influenced by varied conditions of environment. The surface layers differ widely in all their characteristics and in their capability of producing crops. The group includes a range in value from some of the most desirable soils of the Corn Belt to poorly drained soils of low productivity.

Crete-Hastings-Idana Area

Geographic setting.—In southern Nebraska and northern and central Kansas, soils over an extensive area have more or less definite zones of clay accumulation in their subsoils. These soils are commonly referred to as claypan soils. The area comprises nearly level interstream divides in which shallow basinlike depressions are common, broken at intervals by valleys with gentle to steep slopes. Surface drainage from the level areas is slow but adequate with the moderate rainfall of the region. The greater part of the area is between the elevations of 1,650 feet and 1,850 feet above sea level.

FIGURE 31.—Profile of Pinal soil showing lime hardpan (caliche).

Climate.—Mean annual precipitation ranges from 25 to 31 inches. The mean annual temperature ranges from 49° in the northern part to 55° F. in the southern part.

Native vegetation.—Mixed short- and tall-grass vegetation.

Parent materials.—The northern part of this area is a loess-covered plain. The soil material is a remarkably uniform floury silt. In the southeastern part the soils overlie shales or limestones.

Soils.—The important soils developed over silty material have been classed with the Crete and Hastings series. The Crete soils differ from the Hastings mainly in the higher clay content of their heavy layer; in most other characteristics their profiles are similar. The surface, or A horizon, is a dark grayish-brown silt loam or silty clay loam and is composed of three layers, a surface mulch, a platy layer, and a granular layer. The B horizon, or upper subsoil, consists of a brown, more or less heavy claypan. This is underlain by a silty material in which lime has accumulated. Below this is the silty parent material. The Idana soils in central Kansas are somewhat heavier in texture at all depths and are underlain by calcareous shale or limestone.

Use.—Wheat, corn, oats, and alfalfa are the principal crops. The soils are better suited to small grains than to corn, as the water supply over the claypan is lost during dry weather, which often occurs during the growing season of corn.

Grundy-Shelby-Parsons Areas

Geographic setting.—These areas present two general types of landscape. In southern Iowa and northern Missouri a loess-covered plain has been partly dis-

sected by erosion, leaving the original surface on comparatively narrow interstream divides. Below these flat ridge tops the slopes toward the drainageways may be either gentle or steep. These slopes are covered to a greater or less extent by a growth of trees and shrubs. The streams are bordered by terraces and flood plains of considerable width. The areas which extend across southwestern Missouri into Kansas and Oklahoma have less striking topography. The surface features have been produced by long-time erosion on beds of sedimentary rocks. The uplands are for the most part undulating to moderately rolling with occasional low escarpments. The stream valleys are shallow with wide belts of alluvial land. These areas lie almost entirely between 700 and 1,100 feet above sea level.

Climate.—Average annual precipitation in different parts of the areas ranges from 32 to 45 inches, and the mean annual temperature from 50° to 56° F. Winters are mild or moderate; summers hot. Rainfall is usually well distributed during the growing season.

Native vegetation.—Tall grasses, bluestem and bunch grass association. Now largely replaced by bluegrass and other pasture grasses.

Parent materials.—Grundy and Muscatine soils are developed from Peorian loess and the Shelby soils from old glacial drift. Soils of the Parsons, Cherokee, and several minor series are developed from shales and the Bates and Summit soils from sandstones and limestones, respectively.

FIGURE 32.—A fair crop of oats on Grundy silt loam. The Grundy soils lie on flat land, and the landscape is broken only by good farm buildings nestled among tall, sturdy trees.

Soils.—The soils of the smooth land in the northern part of these areas belong to two principal groups, the Grundy and the Muscatine. These soils have very dark grayish-brown or nearly black surface layers underlain by mellow, granular dark-colored layers. At a depth ranging from 24 to 30 inches the Grundy surface soils overlie heavy plastic gray or mottled clay. The clay content does not increase greatly with depth in the Muscatine, but a gray or mottled lower subsoil layer indicates intermittently poor drainage. Associated with the Grundy soils and exceeding them in area are the Shelby soils. These soils have dark grayish-brown surface layers and brown or yellowish-brown gritty subsoils. The underlying parent material is glacial drift. The Parsons soils of the southern areas have moderately dark grayish-brown surface layers and heavy claypan subsoils. The Cherokee soils are similar to the Parsons with the exception of the lighter color of their surface soils and lower productivity. Within these areas, other soils of less extent such as those of the Summit and Bates series are more productive than the Parsons soils.

Use.—The areas of smooth land (fig. 32) are for the most part in cultivation. The Grundy and Muscatine types hold a high place among the corn soils. The Parsons soils are not so well suited to corn but are used for the production of hay grasses and small grains, especially oats. Some cotton and grain sorghums are grown in Oklahoma. The Cherokee soils are not highly productive and a large proportion of the land is kept in grass for hay or pasture. The Grundy, Muscatine, Parsons, and Cherokee soils are naturally poorly drained, but, with the exception of the Cherokee soils, they have been drained. All soils of these areas are acid and are usually improved by lime. The application of commercial fertilizers, especially those rich in phosphates, shows good results. The Shelby soils vary in value and use according to topography. A large part of their area is too steep for farming and is used for pasture. On the smoother part, corn, oats, timothy, and clover are the principal crops. Some cotton and grain sorghums are grown in Oklahoma. The Shelby soils are subject to rapid erosion and their protection is a serious problem.

Putnam-Vigo-Clermont Areas

Geographic setting.—In the southern parts of Ohio, Indiana, and Illinois, and northeastern Missouri are areas of flat topography at elevations ranging from about 400 to 1,100 feet. The soils have developed under the influence of permanently or seasonally poor drainage conditions. The surface soils are light-colored and the subsoils are heavy, tough, and impervious.

Climate.—Average annual precipitation ranges from 37 to 42 inches. The number of days without killing frost averages about 180. Summers are rather hot and winters moderate to cold.

Native vegetation.—The area in Ohio and Indiana was covered by a timber growth of oaks, ash, gum, elm, and hickory. In Illinois and Missouri the flat uplands were treeless or very sparsely timbered, and had a cover of tall grasses.

Parent materials.—The Putnam soils are developed from a silty material, presumably loess. Other soils of the group are developed from glacial till mainly of the Illinoian stage, covered in places by loess.

Soils.—The dominant soils of the area are those of the Putnam series in Missouri, the Vigo and associated soils in Illinois and Indiana, and Clermont soils in Ohio.

Vigo soils are the gray soils of the flats. Vigo silt loam, the representative type, has a surface layer of gray floury silt loam about 10 inches thick, over an upper subsoil, 12 to 24 inches thick, of heavy compact columnar silty clay loam—gray mottled with brown; below this is a variously mottled heavy silty clay loam. The upper layers of these soils are deficient in organic matter and are strongly acid. The Clermont soils differ from the Vigo in the greater thickness of the silty surface layers. The Putnam soils have gray to moderately dark gray surface soils, subsurface layers of light-gray silt, and heavy mottled claypan subsoils. A number of better drained soils occur along the slopes of streams which have carved valleys through the soils of this area.

Use.—The dominant soils have poor surface and internal drainage. Surplus water does not drain away in wet seasons before crops are damaged. The claypan layers also prevent the penetration of roots and reduce the ability of the crops to withstand drought. Corn is the principal crop on these soils, but average yields are low. Wheat, oats, and timothy are grown on the Clermont and Vigo soils, with yields depending on the rainfall. The Putnam silt loam, which is more productive than the other soils, produces fair crops of corn, wheat, and hay grasses. The soils are too acid to produce alfalfa or clover. Over the entire area the tendency in recent years has been to discontinue the growing of cultivated crops and to keep the land in hay or pasture grasses.

San Joaquin-Madera-Redding Areas

Geographic setting.—The San Joaquin, Madera, Redding, and similar and associated soils occupy gently sloping valley plains and upland stream terraces in the northern part and along the eastern margin of the central valley in California. They lie between the Holland and Sierra soils of the Sierra-Nevada foothills and the Fresno, Pond, and alluvial soils of the lower, flatter valley floor. In eleva-

tion they range from about 30 to 600 feet above sea level, the San Joaquin and Madera soils occupying the lower and the Redding the higher elevations. Regional drainage is generally adequate except at times of heavy rainfall, but the surface has a micro-relief of low hummocks and depressions which obstructs surface drainage. Internal drainage is also poor and water stands for long periods during the rainy season (fig. 33).

Climate.- Arid to subhumid, with mean annual rainfall of less than 10 inches in the southern to more than 30 inches in the more northern areas, with long, hot, rainless summers with low relative humidity, and mild, moist to wet winters, absence of snowfall, and a growing season in excess of 240 days.

Native vegetation.—Originally tall grasses with scattered oaks on the Madera and San Joaquin. Arid shrub vegetation with digger pine, manzanita, and ceanothus on the more elevated northern areas of Redding soils.

Parent materials.—Old stream-terrace and alluvial-fan deposits derived from wide range of crystalline and sedimentary and metamorphosed rocks.

Soils.—Surface soils are rich brown to pale reddish brown and brownish red, of low organic matter content, and subsoils are compact, heavier textured, highly colloidal and plastic, of blocky to prismatic structure resting on iron-and-silica-cemented, brown to red hardpan at 12 to 40 inches. Surface and subsoils mildly to strongly acid in San Joaquin and Redding; neutral in the Madera with more fragmental and less firmly cemented hardpan with lime infiltrations.

Use.—The San Joaquin and Redding soils are used mainly for dry-farmed wheat and barley and for pasture. Figs and citrus fruits are grown locally where the soil is improved by breaking up the impervious hardpan by explosives. The Madera soils have a somewhat wider use including deciduous fruit growing, dairying, and general farming under irrigation. Extensive economic use of these soils is limited by water supply for irrigation and by the impervious hardpan to dry-farmed and more shallow-rooted crops.

Figure 33.—Profile of San Joaquin soils in the San Joaquin Valley, Calif. Owing to the limited water supply for irrigation and the iron-and-silica-cemented hardpan layers, these soils are best adapted to grass and drought-resistant shallow-rooted crops. The hardpan layer is indicated by the letter "a". The nearer to the surface it occurs the less productive is the soil.

Wilson Area

Geographic setting.—Wilson and associated soils occupy a belt of smooth undulating country in the east edge of the so-called Blackland Prairies of eastern Texas. Drainage is good.

Climate.—Warm-temperate and humid. Summers long and hot; winters short and mild. Average annual rainfall 35 to 40 inches.

Native vegetation.—Tall bunch grasses, comprising species of *Andropogon* and others, and some grama grass.

Parent materials.—Calcareous clays and marls.

Soils.—Wilson and Crockett soils predominate. They are dark-colored, noncalcareous soils over substrata of stiff calcareous clay. Wilson soils are heavy, hard, and compact when dry, and hard to cultivate. Crockett soils are darker and have less compact consistence.

Use.—Wilson and Crockett soils are highly productive and are used for cotton, corn, sorghums, and other feed crops. These soils occur on the same prairies as the Houston soils, but are considered less productive and more difficult to cultivate.

RENDZINA SOILS

The term "Rendzina" has been applied to an intrazonal group of soils with dark-gray or black surface layers overlying soft, light-gray or white highly calcareous material. These soils develop from chalk, soft limestone, or marl and may be regarded as immature. They have derived large amounts of black organic matter from a grass vegetation. The most extensive soils of this group are in the black lands of northern and central Texas and the black prairies of Alabama and Mississippi. Cotton, corn, and alfalfa are the principal crops. Yields are generally better than the average for the regions in which these soils occur. Other areas of Rendzinas are in hilly or mountainous sections of the coastal region of

FIGURE 34.—Typical view of the Diablo soils showing rolling to hilly relief, open scattered growth of live oaks, grass, and harvested grain hay. These nonirrigated soils are important for growing wheat, barley, and grain hay and for dairying and livestock raising.

California. They are used largely for grazing, although dry-farming is important in places.

Diablo-Catron Areas

Geographic setting.—The Diablo soils occur in the coastal section of California in association with the Altamont and Los Osos soils, while the Catron occupy extensive areas in northwestern Arizona. The Diablo soils occupy smoothly rolling, hilly areas in which slopes are often steep but with infrequent rock outcrops (fig. 34). The Catron soils are stony and interrupted by outcropping ledges, abrupt cliffs, and deep, stream-carved canyons. The Diablo soils occur at elevations of a few feet to 2,000 feet above sea level; the Catron soils mainly at elevations of 2,000 to 6,000 feet. The areas are thinly populated and occupied mainly by grain and stock ranches or public range.

Climate.—Mediterranean type of climate with average annual rainfall about 15 to 25 inches, long, hot, rainless summers with occasional fog, and mild, wet winters in Diablo areas. Continental climate of about the same average annual rainfall of more even distribution with some snow in Catron areas.

Native vegetation.—Grassland with scattered oaks and brushy areas in the Diablo soils and piñon-juniper-grassland association in the Catron soils.

Parent materials.—Highly calcareous shales and sandstones and impure limestones in the coastal areas and harder limestone bedrock in Arizona.

Soils.—Dark brownish-gray or dark grayish-brown to black surface soils, with relatively high organic matter content and loam to clay texture, plastic when wet but shrinking, cracking, and developing a cloddy or granular structure during dry periods. Diablo soils have surface soils leached of free lime but alkaline in reaction, underlain at a depth of 8 to 15 inches by dark-brown or grayish-brown to gray, compact, heavy-textured subsoils of faint to distinct prismatic structure containing gray mottlings, seams, and nodules of lime. Catron soils are mildly to moderately calcareous, and in the more mature developments are underlain at a depth of about 10 inches by reddish-brown to dull red calcareous clay loam or clay, compact, prismatic in structure, and with mottlings and nodules of lime which become more pronounced with depth and may pass into thin cemented caliche hardpan on top of bedrock at depths of 15 to 30 inches.

Use.—The Diablo soils are extensively utilized for dry-farmed grain and hay, and for pasture in dairying and stock raising, with more intensive use in the growing of beans, table corn, and peas where favored by irrigation or rainfall and markets. The Catron soils are little used for cultivated crops but are important for grazing of livestock.

Houston-Austin-Denton Areas

Geographic setting.- Houston, Austin, Denton, and associated soils occupy large areas of undulating to rolling prairies in central and northeastern Texas and central-southern Oklahoma. They comprise most of the Blackland Prairie and Grand Prairie. The elevation ranges from 400 to 800 feet above sea level.

Climate.- Warm-temperate and humid. Summers long and hot; winters short and mild, with a mean temperature of 40° and 50° F. Average annual precipitation, largely rain, is 30 to 40 inches. Frost-free season 220 to 260 days.

Native vegetation.- Largely tall bunch grasses and smaller grasses, such as grama. Shrubs and small trees on some of the thinner soils.

Parent materials. Limestone in the Grand Prairie (western part) and marls and chalk in the Blackland Prairie (eastern part). In Oklahoma some of these soils (Durant) are from sandstone and shale.

Soils.—These soils lie in prairie country; however, they are not true Prairie soils but rather Rendzinas. They have the dark color and high content of organic matter that characterize Prairie soils, but are calcareous throughout. The development of a normal Prairie-soil profile has been retarded by the calcareous nature of the parent material and by erosion, which has proceeded nearly as fast as leaching, thus removing surface soil before it has had a chance to become greatly leached. The surface soils are mostly of brown or black clay--sticky when wet, but on drying breaking into fine grains giving a mellow crumbly consistency. Subsoils are of brown and yellow clays, heavy but allowing ready penetration of water, air, and plant roots. On smooth-lying areas the soil is quite deep but on the steeper slopes it is thin, owing probably to a combination of erosion and lack of penetration of moisture.

Houston soils are dominant on the Blackland Prairie, and there are smaller areas of Austin, Sumter, and Ellis soils. Wilson and Crockett soils (Wilson area, p. 1105) occur along the east edge of this belt. Houston soils are dark colored, deep, calcareous, and highly productive. Sumter and Ellis soils and much of the Austin are thinner, sometimes lighter colored, and less productive. Austin soils, developed from chalk, are very granular.

San Saba, Denton, Crawford, and Brackett soils are the principal soils of the western or Grand Prairie section. These soils are developed from limestone, and large areas are very shallow, stony, and lacking in definite soil-profile development. Denton soils are extensive. They are brown, mostly shallow soils. Crawford soils are characteristically red. San Saba soils, lying mostly on flat land, are black in color. Shallow and stony types or phases of the above-named series, the soils of the Brackett series, and rough stony land, all are nonarable and cover a large total area. Brackett soils are very shallow, light-colored soils consisting largely of whitish calcareous material with very little soil development. The soils of the Grand Prairie and a number of other soils, such as the Durant, brown noncalcareous Prairie soils, occupy the part of this soil area that lies in southern Oklahoma.

Use.—The Blackland Prairie is one of the more intensively farmed sections of Texas. Probably between 60 and 70 percent of the land is used for crops. Minor

areas are used for grazing of farm livestock. Cotton, the principal crop, occupies 40 to 50 percent of the cultivated land. Corn and feed crops are also important, and in some places much wheat and oats are produced. Farms average from 85 to 110 acres in size in various counties. Yields are good except on some of the more steeply sloping lands with thin or badly eroded soils, such as soils of the Ellis and Sumter series and shallow phases of Houston and Austin soils. The land supports a relatively thick population and, in places, a fairly high standard of living, though the proportion of farms operated by tenants is large and many of these do not have a high living standard.

In the Grand Prairie, to the west, a much smaller proportion (20 to 35 percent in various counties) of the land is cultivated. The proportion of cropland is greater in the northern section. The more important crops are small grains, cotton, sorghums, and other feed crops. Stock farming and ranching are important, especially where the soils are thin and stony. Year-round grazing and browse is afforded for livestock, and areas of deeper soils are used for production of feed crops or cotton. The latter is grown on less than one-third of the cropped area. Native grasses are highly nutritious. On the thinner soils shrubs and small trees afford valuable browse for cattle, sheep, and goats. Average size of farms in various counties ranges from 180 to 400 acres. The deeper soils are naturally productive but owing to irregular rainfall yields are less certain than on the Blackland Prairie. On many of the farms, especially those operated by owners, a good standard of living is maintained.

Kettleman-Linne Areas

Geographic setting.—The Kettlemen-Linne soils occur mainly in a hilly belt between the central-southern part and the coast of California at elevations of 1,200 to 3,000 feet. On the east they are associated with the lower lying Desert soils of the west side of the San Joaquin Valley, and on the west with the more humid Diablo and the Altamont-Los Osos-Cayucos soils. Local areas of closely related Nacimiento, Shedd, and Zaca soils are included, and isolated areas too small to show on the small-scale map occur throughout the central and southern and more inland coast ranges. They occupy smooth and rolling to steep hilly and mountainous, areas dissected and eroded, with frequent rock outcrop and narrow canyonlike stream valleys in the eastern and more elevated parts.

Climate.—Subhumid to semiarid with mean annual rainfall ranging from 10 to 25 inches. Summers are warm and rainless, being warmer and drier along the eastern margin; winters mild with frequent rain and fog. Wind movement is gentle. Average frost-free season ranges from 180 to 210 days.

Native vegetation.—Mainly tall grasses, with scattered oaks, and with brushy areas in sheltered localities and at the higher elevations.

Parent materials.—Calcareous shales and sandstones and impure limestones.

Soils.—Brownish-gray or dull gray calcareous surface soils of low organic matter content, friable and granular, often with abundant irregular fragments of rock, over slightly to moderately compact, lighter colored highly calcareous subsoils with imperfectly developed prismatic structure. Sandy loam to clay loam textures dominant; bedrock occurs at depths ranging from a few inches to 60 inches. Erosion is active, especially on the steeper slopes.

Use.—The Linne soils are largely under cultivation to dry-farmed wheat, barley, and grain hay, with some areas devoted to almonds. The rest, as well as most of the more arid and lighter colored Kettleman soils, are utilized mainly for grazing of sheep and cattle. The soils are fertile, but productivity is limited by low rainfall, adverse topography, and lack of water for irrigation. Dry farming is mostly in large tracts with modern mechanized equipment. Growing of nut or fruit crops has been only partially successful.

Sumter-Vaiden Area

Geographic setting.—The Sumter-Vaiden soil area comprises the so-called Black Belt or prairie region of Alabama and Mississippi. The land consists of flat, undulating, and gently rolling broad ridges with intervening broad flat valleys bordered by gentle slopes. In places the surface is hilly and broken, but most of the area lies favorably for farming. Except in the flatter areas the natural surface

drainage is good, but the internal drainage is slow owing to the impervious character of the subsoils. Sheet and gully erosion have been severe, in many places removing all the soil and exposing white limestone material.

Climate.—Considerable variation exists in the climatic conditions in the region. In Montgomery County, Ala., mean annual temperature is 65° F., rainfall 50 inches, frost-free season 247 days; whereas in Pontotoc County, Miss., mean temperature is 61°F., rainfall 48 inches, frost-free season 214 days. Winters are mild; summers, long and hot. The grazing season is long.

Native vegetation.—Calcareous soils supported short grasses and legumes, whereas the acid soils in part supported a growth of post and scrub oak, hickory, sweetgum, black gum, and shortleaf pine.

Soils.—Practically all of the soils in this area have clay surface soils and extremely heavy clay subsoils. They are very tenacious and sticky when wet and when dry are hard, intractable, and tend to crack and shrink. There are two important groups of soils: (1) Calcareous soils, and (2) acid soils. Calcareous soils include the Sumter, Houston, and Bell, and are developed from white soft limestone or Selma chalk. The highly calcareous Sumter soils, known as light prairie, predominate. They have yellowish-gray surface soils and grayish-yellow or creamy-white subsoils, usually shallow over limestone. Houston soils are dark gray to black and subsoils are brownish-yellow to drab. The black color is due to the preservation of organic matter in the soil colloids through the agency of lime inherited from the parent material. Bell soils, occurring at the bases of slopes and on terraces, have black clay surface soils and bluish-black to steel-gray clay subsoils.

Acid soils include Vaiden, Eutaw, and Oktibbeha. Vaiden soils are known as yellow prairie, Eutaw as crawfish prairie, and Oktibbeha as red prairie. These soils are developed from beds of heavy clays underlain at 4 to 8 feet by calcareous materials.

Use.—Prior to the arrival of the boll weevil about 1914, cotton was extensively grown. These soils are not well suited to cotton under boll weevil conditions. Main crops are hay, mainly Johnson grass, and corn. Alfalfa was formerly grown on a commercial scale. Sweetpotatoes, okra, peanuts, cowpeas, oats, sorgo, and ribbon cane are grown for home use and canning. *Melilotus* and black medic clover provide good pasture. The consensus of opinion of the best agriculturists is that the most profitable use of these soils under present economic conditions is for pasture and the production of hay crops and corn in connection with livestock raising and dairying.

Victoria-Goliad Areas

Geographic setting.—The Victoria, Goliad, and associated soils lie in the Rio Grande plain section of the western Coastal Plain, on smooth, nearly flat to gently rolling areas. There are only very small strips of rough, steep, or hilly land, which occur mostly along stream valleys. The plain rises from sea level at the coast to about 800 feet in the northwest.

Climate. Warm-temperate and subhumid. Summers are long and hot; winters, short and mild, with an average temperature of 50° to 60° F. The average frost-free season ranges from 260 to 300 days in various places. Average annual rainfall, 20 to 30 inches. The southern part, bordering the coast and the Rio Grande, is subtropical, and frosts and freezes occur only at infrequent intervals in the winter. Some winters are practically frost-free.

Native vegetation.—Largely a heavy growth of short grasses such as mesquite, buffalo grass, and grama, and scattered small trees and shrubs, including mesquite, live oak, and various other shrubs, many having spines and thorns.

Parent materials.—Calcareous clays (Coastal Plains deposits).

Soils.—Victoria, Goliad, Orelia, Monteola, and Clareville soils are the principal dark-colored soils of this area. These soils are generally deep and for the most part are of heavy texture although fine sandy loams are extensive in places. Even the heavier soils are mostly granular and crumbly. Some of the more uneven or steeper lands have lighter colored or redder and thinner soils.

Victoria soils have very dark brown or black granular surface soils over dark-brown heavy upper subsoils and yellowish or grayish-brown clay subsoils. At about 30 to 40 inches is encountered the substratum of light yellowish- or grayish-brown friable clay containing much white soft limy material, some of which forms soft concretions or nodules. The soil and subsoil are distinctly calcareous through-

out. These soils are Rendzinas—soils which, owing to the very high lime content of the parent soil material, have not yet developed the typical mature soil profile of the region. Clareville soils are associated with the Victoria but have slightly more accumulation of lime in the subsoil and are not calcareous above the layer of accumulation. Monteola soils are similar to the Victoria but have a more pronounced subsoil lime accumulation.

Goliad soils have black surface soils over red or reddish-brown crumbly clay subsoils, which below a depth of 3 to 5 feet rest on white chalky calcareous beds. They are typically of pedocalic development in that they have the well-defined horizon of carbonate of lime accumulation in the profile. The surface is undulating to rolling and some of the land has been subject to serious erosion. Some large areas are shallow and unfit for farming.

Orelia soils have black or very dark brown, mostly heavy surface soils and dense dark-gray or dark-brown clay subsoils, of a claypan character, underlain by a light-gray layer of carbonate of lime accumulation.

Use.—These soils are inherently fertile, and when moisture is adequate they are highly productive and suited to many different crops. Along the eastern border of this belt rainfall is usually sufficient for satisfactory crop production, but at the west it is so low that crops can seldom be grown successfully without irrigation.

Much of the land is in large ranch holdings, and livestock raising on the range is perhaps the most important activity. However, where rainfall is adequate or irrigation is developed, much of the land is in crops. In some counties only 1 to 2 percent of the land is cultivated, in others, 20 to 40 percent. Average size of farms (or ranches) in different counties ranges from 200 to 2,000 acres, and some are much larger. Where fruit and truck crops are grown under irrigation most of the farms are less than 100 acres.

The principal crops are cotton, corn, forage, and feed crops (largely sorghums), and, in places, market-garden crops and fruits. Near the Rio Grande, citrus fruits and winter vegetables are grown under irrigation from the river. Elsewhere irrigation water is obtained either from wells or local streams. Future land development depends largely on the development of adequate supplies of water.

The area supports a good standard of living for most of the people occupying the land.

WIESENBODEN, GROUND-WATER PODZOLS, AND HALF BOG SOILS

These miscellaneous intrazonal soils have in common poor drainage, high water table, and a more or less waterlogged condition. The areas are usually low and flat. Wiesenboden and Half Bog soils are generally dark in color and contain large quantities of, or are made up largely of organic matter, whereas Ground-Water Podzols are comparatively light in color and poor in organic matter. The Wiesenboden are meadow soils with a native vegetal cover of grasses and sedges; Half Bog soils have a growth of sedges, reeds, brush, or trees; and Ground-Water Podzols have a forest cover under virgin condition. Wiesenboden and Half Bog soils are commonly underlain by light gray, blue-gray, or greenish-gray glei layers. Ground-Water Podzols have a thick ashy-gray soil layer over a dark-brown or nearly black, tough or more or less cemented subsoil. The last are generally of low inherent productivity, whereas the soils of the other two groups are usually fairly or highly productive if drained and properly managed.

Coxville-Portsmouth-Bladen Area

Geographic setting.—This area includes the flatwoods or seaward portion of the Coastal Plain from Norfolk, Va., to the Altamaha River in Georgia. Much of the constructional form of the land as laid down by the sea is maintained. The land is dominantly flat and almost level to undulating, interspersed with numerous swamps, bays, pocosins, low sand ridges, tidal marsh, and strips of coastal beach, and the area is indented by tidal streams or estuaries. Elevation ranges from sea level to about 50 or more feet above. Some of the higher lying lands have been invaded by numerous streams and are fairly well drained, but the greater part of this area is naturally poorly drained.

Climate.—Oceanic, mild, warm, humid; considerable difference in frost-free season between the northern part and the southern part. At Norfolk, Va., mean temperature is 59° F., rainfall 44 inches, frost-free season 237 days; at Savannah,

Ga., mean temperature is 66°, rainfall 51 inches, growing season 284 days. Rainfall is greater along the coast than along the inland border of this area.

Native vegetation.—Longleaf and shortleaf pine, oak, hickory, dogwood, sourwood, holly, sweetgum on better drained areas, whereas hardwoods, gums, and cypress prevail in the swamps.

Parent materials.—Soils underlain by and developed from beds of unconsolidated sands, sandy clays, and clays of recent geological origin. These materials have had a direct effect upon the texture and consistence of the soil and subsoil. Practically all of the soils are characterized by mottled subsoils which indicate poor aeration and drainage.

Soils.—Most of the soils are light-colored and contain a small amount of organic matter, although there are large areas of black soils highly charged with organic matter. All the soils range from medium to very strongly acid in reaction.

The Coxville soils cover a large acreage. They are characterized by medium-gray to dark-gray surface soils, subsurface layers of light gray, and heavy fine sandy clay to clay subsoils of light gray mottled with yellow, noticeably splotched with bright red at a depth of 24 to 30 inches. Closely associated with the Cox-

FIGURE 35.—Cabbage on Coxville fine sandy loam near Charleston, S. C.

ville are the Lenoir soils, slightly better drained, lighter in color, and having heavy compact subsoils. Bladen soils have gray to brown surface soils and are distinguished by their plastic fine sandy clay to clay subsoils of steel gray mottled with brownish yellow.

The Portsmouth, Bayboro, and Hyde soils have black surface soils containing large quantities of organic matter and are underlain by sandy clays in the Portsmouth and heavy plastic clays in the Hyde and Bayboro soils.

On better drained lands are Norfolk, Ruston, and Dunbar soils, the Dunbar being intermediate in color, drainage conditions, and consistence between the Norfolk and Coxville. Small areas of Leon, St. Lucie, Onslow, Plummer, Eulonia, and Fair Hope soils are of common occurrence. In addition there are extensive areas of soils developed on the terraces and alluvial bottom lands, and also peat, muck, and swamp.

Use.—A comparatively small percentage of these soils is under cultivation. General farming and the production of highly specialized crops are characteristic

of the area. The main cash crops are peanuts, cotton, tobacco, and a variety of truck crops. The raising of hogs and the growing of corn in the northern part of the area are important. The main trucking sections are in the vicinity of Norfolk, Va., New Bern and Wilmington, N. C., Charleston and Beaufort, S. C. (fig. 35), and Savannah, Ga. A large acreage is devoted to strawberries in the vicinity of Chadbourn and Rocky Point, N. C. Other large areas are planted to soybeans, velvetbeans, and Austrian Winter peas, and pecan trees are being set in some localities. Extensive areas of fairly good soils await development. They can be reclaimed by artificial drainage with canals and open ditches. There is practically no erosion throughout this part of the Coastal Plain.

Hockley-Katy Areas

Geographic setting.—Hockley, Katy, and associated soils occupy a discontinuous, narrow belt of flat or gently undulating prairie land in southeastern Texas, at the northern margin of the coast prairie where it merges with the Red and Yellow timbered soils of the Coastal Plain. Smaller areas not shown separately on the map lie scattered over the coast prairie in close association with Lake Charles and Crowley soils. Both surface drainage and subdrainage are poor.

Climate.—Warm-temperate and humid to subhumid. Winters are short and mild with an average temperature of 50° to 60° F., summers long and rather hot. Average annual rainfall ranges from 36 to 40 inches.

Native vegetation.—Abundant growth of coarse bunch grasses, largely species of *Paspalum*, *Andropogon*, *Panicum*, and other tall grasses.

Parent materials.—Coastal Plain deposits of clay or sandy clay, containing little or no carbonate of lime.

Soils.—The soils have light-colored (light grayish-brown to gray), more or less sandy surface soils over gray-mottled, rather dense heavy subsoils. They are poorly drained, acid in reaction, low in organic matter, rather deficient in some of the essential plant nutrients, and low in natural productivity for farm crops.

Edna, Hockley, and Katy soils are most important, and fine sandy loam is the principal soil texture. The surface soils of the various series are all somewhat similar. Edna soils have gray, dense, tough subsoils almost impervious to downward movement of water. Hockley soils have similar but slightly darker surface soils than the Edna, and heavy but less dense subsoils, yellow with gray mottlings. Katy soils differ chiefly in having mottled red, yellow, and gray subsoils that are heavy but fairly permeable.

Use.—Land used principally for grazing cattle. The cultivated acreage is not large, probably not over 10 percent. The chief crops are hay, forage, and grain sorghums, and there are smaller areas devoted to production of rice, cotton, corn, and truck crops. Though productivity is naturally low, fair crop yields are obtained where adequate drainage is provided, organic matter is added, and fertilizers are used.

Kittson-Pelan Area

Geographic setting.—This area lies in northwestern Minnesota just east of the area of Fargo and Bearden soils of the Red River Valley and extends northward across the Canadian boundary. It is within the basin of glacial Lake Agassiz, and is part of the plain formed by the old lake bed. Minor features of relief are stream trenches, low sand or gravel ridges, and low dunelike areas of sand which rise only a few feet above the level of the plain. The elevation ranges from about 950 feet to 1,100 feet above sea level.

Climate.—Subhumid; winters long, cold, with extreme minimum of about −50° F.; summers short and warm. Average annual rainfall slightly above 20 inches, 75 percent of which falls between April 1 and September 30. The frost-free period is 100 to 110 days, but the growing season for hardy crops is longer, although frosts may occur in the bogs at any time during the year. The area is definitely less subject to drought than the region to the westward.

Native vegetation.—Mixed grassland and woodland. The tree growth is generally low and in clumps with aspen and willows dominant. Bog areas are in part open and in part timbered with tamarack, black spruce, and swamp hardwoods.

Parent materials.—Largely glacial drift of late Wisconsin stage—lake-washed

calcareous till for the most part; lacustrine deposits and beach ridges; and smaller areas of sand assorted and deposited by water and reworked by wind.

Soils.—Complexly intermixed. For the most part dark-colored owing to poor natural drainage, grass vegetation, and the highly calcareous nature of the parent materials. The Kittson soils are dark-colored, of heavy to medium texture, rich in organic matter to a depth of 6 to 12 inches. The subsoil is generally gray or mottled heavier material which grades at a depth of about 18 inches to the calcareous glacial till substratum. The Pelan soils are similar to the Kittson but have a noticeable layer of gravel and cobbles, generally just beneath the dark-colored surface soil. The very sandy soils of the area, classified as Poppleton soils, are moderately dark in color, loose in structure, and when under cultivation subject to wind drifting. A considerable portion of the area is covered by peat bogs, the peat being generally brown and undecomposed.

Use.—Much of the land under natural conditions was poorly drained. Such land is chiefly suited to wild hay and pasture. Artificially drained lands and smaller areas with better natural drainage are cropped to tame hay, small grains, flax, corn for silage, and potatoes. Hay (including wild hay) is the dominant crop. The use of the land for hay, forage, and pasture leads naturally to a dairy type of farming although the market for whole milk is restricted. Weeds present a difficult problem, particularly Canada thistles and sowthistles, and have led to the abandonment of some cultivated lands.

FIGURE 36.—Profile of Leon fine sand. Note the thick layer of nearly white fine sand and the dark-colored organic hardpan.

Leon-Bladen Areas

Geographic setting.—The Leon-Bladen soil areas comprise the greater part of the flatwoods of Florida, southeastern Georgia, and southeastern Mississippi. Leon soils occupy by far the largest area, something like 3 to 4 million acres, whereas the Bladen soils are small in extent but are the most important agricultural soils. The area ranges from sea level to 50 or more feet above in elevation. It is characterized by dominantly flat to undulating surface, numerous low sand ridges and hummocks, water and grass ponds, swamps and tidal marsh. There are numerous tidal streams and estuaries. Natural surface drainage is poor except for the sand ridges. The hardpan layer under the Leon and St. Johns soils prevents the free movement of rain water downward and capillary rise of water upward.

Climate.—Oceanic, warm to semitropical. Considerable difference exists in climatic conditions in different parts of the areas. At Velona, Ga., mean temperature is 66° F., rainfall 49 inches. At Jupiter, Fla., mean temperature is 74°, rainfall 60 inches. Frost-free season ranges from 260 to 310 days, with very little killing frost in the southern extremity of the region. Rainy season May to

October, dry season November to April. Climate favorable for the production of winter truck crops, citrus fruits, guavas, and coconuts.

Native vegetation.—Longleaf pine, undergrowth of saw palmetto, runner oak, wire grass, broom sedge, gallberry, and dogfennel on better drained areas. In the swamp areas, cypress and gum predominate. On the Bladen areas hardwoods, cabbage palmetto, magnolia, bay, and holly.

Parent materials.—Recent Coastal Plain deposits, unconsolidated beds of sands, sandy clays, and heavy clays. The soils range from medium to strongly acid, the Leon and St. Johns being the most acid in reaction; contain a small amount of organic matter and mineral plant nutrients.

Soils.—Characteristic feature of the Leon soils is a well-defined black to dark-brown hardpan layer consisting of fine sand or sand cemented by organic matter (fig. 36). The surface soil is light-gray to gray fine sand, 3 to 5 inches thick, underlain by light-gray to almost white fine sand to a depth of 12 to 30 inches,

FIGURE 37.—Typical growth of longleaf pine and saw palmetto on Leon fine sand. Pines make a good growth on this soil and soon attain sufficient size to be boxed for turpentine. Probably the best use for the Leon soils is for the production of trees and pasture.

resting on the hardpan. The hardpan layer is usually 3 to 12 inches thick and underneath it is a brown fine sand grading into gray fine sand. The St. Johns soils differ from the Leon in being more poorly drained and having a black surface layer.

Bladen soils are distinguished by dark-gray to brown surface soils, ranging in texture from loamy fine sand to heavy clay, and by subsoils of heavy, sticky, fine sandy clay, or heavy plastic clay, steel-gray mottled or streaked with yellow or brownish yellow. Scattered areas of poorly drained black soils are included in the Portsmouth and Hyde series; areas of light-gray soils in the Plummer series; and ridges and knolls of sands and fine sands, in the St. Lucie, Lakewood, Norfolk, Blanton, and Palm Beach series. Areas of Eulonia and Fairhope soils are characterized by their light-colored surface soils and heavy mottled clay subsoils. In addition there are extensive areas of swamp, tidal marsh, and coastal beach.

Use.—Only a small acreage of the soils of this area is used for farming, the greater part being devoted to pasture and forestry. Very little of the Leon soils except in the vicinity of Sanford, Fla., is cultivated, and here the soils are used for the production of celery and truck crops under irrigation. Bladen soils are inherently good soils and are rightly considered the best soils in Florida and southeast Georgia for the growing of potatoes. They also produce good yields of cabbage, corn, sweetpotatoes, velvetbeans, and soybeans. Plummer, Portsmouth, and Parkwood soils, where drained, are used for winter truck crops, such as peppers, eggplant, tomatoes, and beans. These crops, together with potatoes and cabbages, receive heavy applications of commercial fertilizer. Some citrus fruit is also grown on scattered areas of included soils. In this area there is a vast acreage of inherently poor soils, which, unless favored by the introduction of some new plants or crops, should remain in forest or be used for pasture, although the pasturage is scanty (fig. 37). The production of naval stores is an important industry and could be extended.

Lake Charles-Crowley Areas

Geographic setting.—Lake Charles, Crowley, and associated soils occupy a discontinuous belt of land in the Gulf Coast prairie of Texas and Louisiana and a smaller area in eastern Arkansas. The country is nearly flat and drainage is poor.

Climate.—Warm-temperate and humid. Summers are long and hot; winters, short and mild. Annual rainfall 35 to 55 inches.

Native vegetation.—Tall bunch grasses and coarse grasses of various genera including *Paspalum*, *Panicum*, *Andropogon*, and others.

Parent materials.—Calcareous clays and marls.

Soils.—Lake Charles and Crowley soils are dominant. Lake Charles soils have dark-colored, noncalcareous soils over limy clay subsoils and substrata. Crowley soils are somewhat similar but have light-colored surface soils.

Use.—Soils fairly productive where drainage is favorable, but owing to prevailing poor drainage much of land is not farmed. Chief crops in the more easterly sections are rice and feed crops, whereas cotton is most important farther west, and other crops are corn, sorghum, and feed crops. These soils do not support as high a standard of living as do darker Prairie soils farther north.

Newton-Maumee Areas

Geographic setting.—The Newton, Maumee, and similar soils are for the most part scattered through the Plainfield-Coloma, Miami-Kewaunee, Toledo-Vergennes, and other soil areas of the Great Lakes region. However, three bodies of land in northern Indiana and Illinois are dominated by these soils to a sufficient extent to warrant their separation on the generalized soil map. These areas occur as broad low plains (fig. 38), the generally flat surfaces relieved only by low ridges of sand or gravel, and shallow incipient drainageways. The general elevation varies from less than 500 to 700 feet above sea level.

Climate.—Average annual precipitation about 35 inches, 50 to 60 percent of which falls in the warm season between April 1 and September 30. Summers are marked by periods of hot weather, when the maximum temperatures range above 100° F.; winters are moderately severe, with minimum temperatures below zero each winter. Average frost-free period, 160 to 180 days.

Native vegetation.—Wet open marshes, with reed, sedge, and grass cover, and drier prairies were dominant. Interspersed areas of dry sandy soils were covered with open stands of small oaks.

Parent materials.—Chiefly sandy materials, laid down by glacial streams in basins and glacial drainageways. Water-laid gravels, silts, and clays are associated and interbedded with the sand deposits. The material is variable in composition, the sand is nearly all quartz, the fine earth is complex in composition, in places calcareous; the gravel is mixed, but mostly quartz.

Soils.—The Newton and Maumee are dark-colored soils, developed under poor drainage in very sandy parent materials. Newton is dark gray to a depth of 8 to 12 inches, with a moderate amount of organic matter, underlain by mottled or gray quartz sand, waterlogged under natural conditions. The Maumee soils are darker colored, definitely higher in content of organic matter, and neutral to alkaline in reaction. A considerable proportion of the soil associated with

and mapped in the Newton-Maumee areas is muck. Soils developed from and underlain by clay are chiefly of the Bono and Toledo series, described in the Toledo-Vergennes area. In the two areas that are entirely in Illinois, perhaps half of the lands consist of brown or very dark gray silt loam underlain by gravel.

FIGURE 38.—Vertical aerial photograph of approximately 1,280 acres in Kankakee Basin, Ind. Farmsteads and cultivated crops occupy land of Newton, Maumee, and associated sandy soils, much of which was too wet for farming before artificial drainage. The Kankakee drainage canal, one of the largest in the United States, is visible in the picture (*a*).

The areas of brown silt loam are well drained, owing to the natural lowering of the water table in recent geological time and the pervious nature of the substratum.

Use.—These lands are in the Corn Belt, and corn is the dominant crop on the better soils. Much of the land has been artificially drained; one of the largest drainage canals in the United States has been dug through the Kankakee Basin

in northwestern Indiana and northeastern Illinois. Small grains, particularly oats, and hay are other important crops. Special crops, such as onions and celery, are raised on the muck areas. The associated drier sands are, to a great extent, left in woodland and furnish some pasturage.

Toledo-Vergennes Areas

Geographic setting.—Toledo, Vergennes, and associated soils occur in 10 areas of considerable size in the Northeastern and North Central States. The two easternmost areas are on the Maine coast; another in the Champlain-Hudson Valley in extreme eastern New York and western Vermont; others are adjacent to Lakes Ontario, Erie, Huron, and Michigan. Elevations range from sea level in Maine to about 800 feet in the Middle West. All these areas are lake or marine plains, nearly flat except where recent stream intrenchment has produced shallow valleys, or where sandy materials have been whipped into low dunes or ridges by wind or water. They are, for the most part, well-developed, prosperous agricultural sections.

Climate.—Continental, cool-temperate, and humid. Summers, moderate to hot. Winters, rather long and cold. Precipitation averages 30 inches over the western part to 40 inches in the eastern part. Frost-free season averages 150 to 170 days.

Native vegetation.—Oak, maple, beech, ash, white pine, elm, and hickory on well-drained areas, and soft maple, arborvitae, willow, and alder upon low areas.

Parent materials.—Lake-laid silts and clays, generally calcareous, or heavy clay till of Wisconsin glacial age. There are some areas with a sandy covering of variable depth over the clays.

Soils.—Dunkirk, Amboy, Ottawa, Schoharie, and Lucas are well-drained soils of the plains adjacent to and near Lake Ontario and Lake Erie; the Caneadea, Fulton, Rimer, Lorain, Nappanee, and Collamer are imperfectly drained soils of this region; and the Toledo, Poygan, Colwood, Saugatuck, Brookston, Paulding, Pandora, Wauseon, Maumee, and Granby are poorly drained soils. These soils are commonly free from gravel although they may contain some in spots.

The Dunkirks are among the more important soils. They are pervious and well drained in spite of the comparative flatness of the surface. The surface soil of the Dunkirk silt loam to a depth of about 7 or 8 inches is brown to grayish-brown friable silt loam of crumb structure, over a friable yellowish-brown subsoil. At about 18 inches and continuing to about 30 inches is a layer of pale yellowish-brown firm or slightly compact material, flecked with gray, grading into less compact material. At an average depth of 40 inches this passes into gray, friable, highly calcareous bedded silts. Amboy soils are similar to the Dunkirk except that they are acid throughout soil and substratum. The Lucas soils are somewhat similar but of much heavier material than the Dunkirk. The subsoils are heavy and tough. Schoharie soils are on reddish-brown or red calcareous silts and clays. Ottawa soils, of deep, fine sandy material, have low water-holding capacity.

Caneadea soils are imperfectly drained, grayish-brown soils over mottled gray and yellow subsoils and olive-yellow to greenish-gray, heavy, massive, cacalreous substrata. Collamer soils are associated with the Dunkirk, lying on the flatter areas. They have a hardpan at 20 to 24 inches, above which is a gray or mottled zone 6 to 10 inches thick. The substratum is friable.

The poorly drained soils, on low flat areas and in depressions, have dark surface soils and mottled subsoils.

Toledo soils have dark brownish-gray or black surface soils over bluish-gray or mottled yellow-and-gray heavy calcareous subsoils. Brookston soils have dark-brown or dark brownish-gray surface soils over yellow-and-gray mottled subsoils. Colwood soils have a substratum of bedded calcareous silts and are associated with the Dunkirk and Collamer. Granby soils have calcareous fine sandy substrata. Saugatuck soils have acid sandy substrata and a ground-water hardpan.

The soils of the Champlain and St. Lawrence lake plains are developed on heavy calcareous materials from slate and limestone. Vergennes soils occupy the more level areas. Drainage is fair, but the soils are not thoroughly oxidized. Undisturbed areas have a thin dark surface layer resting on a gray floury material about 5 inches thick, passing into brown clay that changes at about 12 inches into a dark bluish-gray clay of massive structure. It is distinctly limy below 20 inches. The Addison soils are well drained and have brown surface soils and reddish-

brown subsoils, passing at about 3 feet into blue-gray calcareous clay. Poorly drained areas (black Vergennes and Livingston soils) have dark-brown to almost black granular surface soils to about 10 inches over calcareous blue-gray clay mottled with yellow and rusty brown. Sheldon soils are developed from deposits of sandy material 20 to 40 inches thick, over the lake-laid clays. They have brown surface soils over yellow-brown subsoils and in places some mottling just above the clay.

Hudson soils are developed on lake deposits of the Hudson Valley derived from slate, limestone, and sandstones. They occupy terraces and are well or imperfectly drained. They have brown or grayish-brown surface soils and yellow-brown or yellow mellow subsoils, grading into bedded gray, blue-gray, and yellow-brown silts and clays. Claverack soils are developed from a sandy overwash over silts and clays.

Orono soils are well-drained soils developed in the Maine coastal section on lake deposits from schist and shales. They have brown or dark-brown surface soils, passing into yellow, rather heavy subsoils into greenish-gray, calcareous clays below 48 inches. Suffield soils occur in this area and in small areas in the Connecticut Valley. They are described with the Wethersfield-Cheshire areas.

Use.—Dunkirk soils are used for a wide variety of crops and are highly productive. They are well suited to alfalfa and to apples. Amboy soils have similar adaptation to the Dunkirk but are less suitable for alfalfa and better for potatoes. Lucas soils are less well adapted to alfalfa and fruit than the Dunkirk. Schoharie soils are used for timothy, clover, alfalfa, wheat, and oats. Ottawa soils are droughty and of low value for farming.

Caneadea, Fulton, and Collamer soils are used mainly for hay (timothy and clover), small grains, and pasture. Some apples are grown on Collamer soils, but they are not so suitable for orcharding as the Dunkirk.

Toledo, Brookston, Poygan, Colwood, Granby, and Saugatuck soils in their native state are suitable only for forest or pasture, but when drained they produce good crops of timothy, clover, oats, and vegetables. The two first-named are largely in the Corn Belt and produce heavy crops of corn, oats, hay, and sugar beets.

Vergennes soils are used for timothy, clover, oats, wheat, barley, and pasture, and, in better drained places, for alfalfa. Addison soils are devoted to a wide range of crops including alfalfa. Black soils included in the Vergennes series and the Livingston soils support a grass cover under natural conditions. When drained they are used for beans, alfalfa, clover, and timothy. Sheldon soils are fairly good general farming soils.

Orono soils are used for general farm crops. Suffield soils are wetter and useful mainly for pasture and hay.

Hudson soils are used for general farming and are rather highly productive. The silt loam is used for timothy, clover, alfalfa, oats, wheat, corn, and vegetables; the silty clay loam, mainly for hay and small grains.

SOLONCHAK AND SOLONETZ SOILS

Solonchak and Solonetz soils are the salty and alkali soils of the arid and semiarid regions of the western United States. They are either poorly drained or have been developed under poor drainage. Solonchak soils contain large quantities of soluble salts, are commonly light-colored, are poor in organic matter, and have a lightly crusted friable granular structure. Solonetz soils are the product of the partial leaching and alkalizing of Solonchak soils, and often occur as spots scattered through the latter. They have a thin surface layer of light-colored leached ashy material over a darker-colored subsoil layer of tough heavy material of columnar structure. The lower subsoil is generally light gray and highly calcareous. Both Solonchak and Solonetz soils are generally largely unfit for agricultural use unless special measures are practical for reclamation. The land has use principally as range for livestock.

Fresno-Pond Areas

Geographic setting.—The Fresno, Pond, and associated soils occur in dry interior valleys of California—mainly in the San Joaquin Valley. The land is comparatively low and gently sloping or undulating to flat. In places, especially on low flats, the surface is bare and crusted with salts while in some of the higher areas of sandy soils the land is highly developed.

Climate.—Arid. Rainfall 5 to 15 inches. Summers long, hot, and dry; winters mild and sunny. The average frost-free season ranges from about 250 to 290 days.

Native vegetation.—Bunch grass on higher areas of Fresno, saltgrass, greasewood, and seepweed on lower areas. Pond soils have sparse grass and desert-shrub cover.

Parent materials.—Alluvial or lake-laid deposits more or less modified or shifted by winds.

Soils.—Light-brown or light grayish-brown soils ranging in texture from sand to clay, over medium to heavy compact gray limy subsoils amounting to a hard-pan in the Fresno soils. Most of the Pond soils and large areas of the Fresno soils are Solonchak or saline soils with salt crusts and granular structure, and there are small spots of Solonetz (alkali claypan). The sandier soils of the Fresno series, which lie higher and are better drained, contain comparatively little salt.

Use.—The salty areas are waste land or have some use for pasture. The better drained and comparatively salt-free areas are intensively cultivated and produce

FIGURE 39.—Typical Solonchak (salty or "alkali" soil) in Utah. The surface is puffy and granular. Vegetation consists of halophytic plants—greasewood and seepweed.

good crops of alfalfa, grapes, peaches, figs, apricots, small fruits, and vegetables. Dry-farmed grains are also grown on rather large areas.

Some of the salty areas may be reclaimed by drainage and washing. The chief needs of the soils are organic matter and nitrogen, which may be supplied in manures and by growing alfalfa and other legumes. Phosphorus may be relatively unavailable in places, and the use of some readily soluble phosphorus fertilizer like superphosphate is desirable in such instances.

Lahontan-Terminal Areas

Geographic setting.—These soils lie in the Great Basin in Utah and Nevada on old lake flats, alluvial bottom lands, and smooth low-lying alluvial fans and terraces. The surface is bare and crusted with salt over large areas—in other places thinly covered with desert shrub or salt-tolerant herbs and grasses. The region is almost uninhabited.

Climate.—Arid. Rainfall 3 to 12 inches. Summers hot and very dry. Winters cold.

Native vegetation.—Greasewood, shadscale, saltbush, seepweed, pickleweed, salt grass. Small areas of higher land have rabbitbrush, sagebrush, and cheat grass.

Parent materials.—Alluvial and lake-laid deposits of fine texture (clay, silt, and fine sand) from wide variety of rocks.

Soils.—Two types of profiles—the saline or Solonchak (fig. 39) (puffy and granular), and alkali or Solonetz ("alkali hardpan"), often intimately mixed. Solonchak (Lahontan) soils, commonly light brown to light brownish gray; white salty crust in places on surface. Surface soil typically granular and fluffy; subsoil moderately compact. Solonetz soils (Terminal) often present in spots scattered through the Solonchak, have light brownish-gray, ashy surface soils, somewhat compact and slick in spots, over coffee-brown, tough, heavy upper subsoils of columnar structure, and light-gray or white limy lower subsoils, in places cemented into a hardpan. The substrata are commonly of dense vari-colored lake-laid clays.

Use.—These areas are largely wasteland. A few small included areas of higher, better drained land are irrigated and produce fairly good crops of alfalfa,

FIGURE 40.—The Walnut silt loam, a shallow soil or Lithosol, in the mountains of western North Carolina.

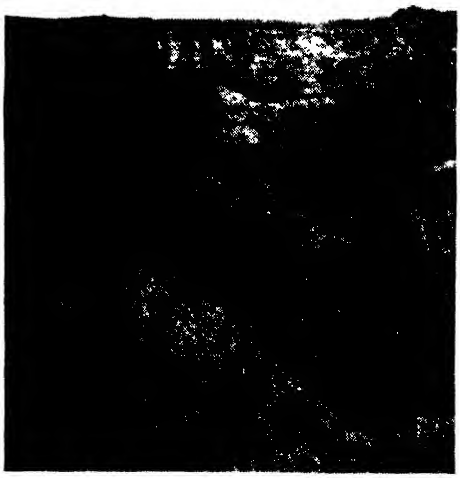


FIGURE 41.—Badlands of South Dakota.

sugar beets, small grains, and potatoes. Narrow alluvial bottoms produce wild hay and pasture. The desert shrub furnishes scant browse, mostly for sheep.

Salty areas can be reclaimed only by providing drainage and flooding the land. Use of gypsum will help to counteract a strong alkaline reaction and to prevent the development of impermeable soil conditions. Barnyard manure and superphosphate are the most efficient fertilizers, and growing of alfalfa in the rotation is recommended.

LITHOSOLS AND SHALLOW SOILS (HUMID)

This group includes immature soils thinly developed over rock formations under conditions of ample to excessive moisture. The soils have a wide range in geographic and topographic distribution. In the eastern part of the United States, they have developed on the Appalachian Mountains and plateaus (fig. 40), the mountains of New England and New York, and the low, relatively flat lands of

Florida. Much of the area is covered with timber. In the Western States these soils are confined to the high mountainous regions where the rocky slopes, thinly covered with soil, are associated with thin stands of timber and with alpine meadows. The parent materials of the soils of this group vary widely in composition, being derived from a great number of igneous, sedimentary, and metamorphic rocks. The soils naturally vary widely in composition and productivity as a result of this variety of parent material and the differences in local conditions that govern the decomposition of rocks and the formation of soil. A comparatively small proportion of the land is cultivated.

Hartsells-Muskingum Areas

Geographic setting.—The Hartsells, Muskingum, and associated soils are in northern Alabama, northwest Georgia, east-central Tennessee, and southeastern Kentucky on the southern extremity of the Appalachian Plateau. The elevation ranges from about 700 feet in places in Alabama to about 2,200 feet above sea level on the Cumberland Plateau in Tennessee, and from about 300 to 1,000 feet above the surrounding country. It comprises comparatively smooth-topped mountains, the largest being Sand Mountain and the Cumberland Plateau, and many elongated ridges and irregularly shaped hills, all of which have steep slopes and in places rocky escarpments. The area is deeply dissected by streams. Natural surface drainage is good to excessive, and sheet erosion and gullying are rather severe on much of the land under clean cultivation and locally on steep uncultivated slopes. Narrow to fairly broad limestone valleys lie between these mountains.

Climate.—Continental. Wide range between temperature of coldest months and hottest period. Mean temperature in Alabama is around 61° F., rainfall 49 inches, growing season 210 days. Farther north on the Cumberland Plateau temperature is lower and growing season shorter.

Native vegetation.—In northern part hardwoods predominate; in southern part, loblolly pine and hardwoods.

Parent materials.—Interbedded sandstones and shales of the "Coal Measures." Highest portions capped with sandstone.

Soils.—These soils are dominantly fine sandy loams to silt loams, low in mineral plant nutrients and organic matter, and medium to strongly acid in reaction. The Hartsells soils are the dominant agricultural soils in this area. They have gray to grayish-yellow surface soils, pale-yellow to grayish-yellow subsurface layers, and yellow to brownish-yellow friable fine sandy clay to silty clay loam subsoils extending to a depth of about 28 to 30 inches, where they are underlain by disintegrated sandstone or shale. The Hanceville soils have brown surface soils and red friable subsoils. Scattered areas of Lickdale soils which are poorly drained have a gray surface and a gray subsoil mottled with yellow or brown. On slopes, extensive areas of Muskingum soils are developed. The subsoils are very thin or lacking in places and the sandstone and shales come near the surface and outcrop frequently.

Use.—Most of the farms are small in size, are owned and operated by white people, and a self-sufficing agriculture is practiced. In Alabama the smooth areas have been cleared and used for the production of corn, cotton, oats, soybeans, cowpeas, peanuts, watermelons, sweetpotatoes, peaches, apples, sorgo, potatoes, lespedeza, and garden vegetables. On the Cumberland Plateau in Tennessee are extensive areas of soil having smooth relief which have not been cleared but could easily be brought under cultivation. Large tracts of land are held by coal and lumber companies and considerable soft coal is mined in Alabama and Tennessee. The Hartsells soils are used to fair advantage, and during the depression the farmers on these soils were in comparatively better financial condition than those on more fertile soils. Muskingum soils are best suited to forestry. Commercial fertilizers are used and crop rotation practiced.

Muskingum-Lehew Area

Geographic setting.—This area comprises that portion of the Appalachian ridges in which red shales and gray shales are interbedded. It consists of one linear irregular body trending northeast-southwest, associated with the Dekalb-Leetonia area which lies on the higher lands to the westward, and the Hagerstown-Frederick areas of the valley lands. The area is made up for the most part of steeply sloping

lands which form the sides of the ridges, in places dissected to a hilly or mountainous terrain. The elevations range from 1,000 to 2,000 feet above sea level.

Climate.—Somewhat variable within the area, due to differences in elevation and exposure. The annual rainfall varies from less than 40 to more than 45 inches, rather uniformly distributed through the year. The winter temperatures at the higher altitudes range down to −25° F., the highest summer temperatures are above 100°. Average frost-free period varies with the altitude and latitude from 140 to 170 days.

Native vegetation.—Chiefly hardwood forest with scattering of pines and hemlock. Dominant hardwood trees were chestnut oak, red oak, white oak, maple, and chestnut. The chestnut has been killed by the blight, the large timber of other species mostly cut out; the present forest is chiefly second-growth timber and brush.

Parent materials.—Red and gray shales and sandstones.

Soils.—The Muskingum soils are shallow soils developed from gray shales described under the Muskingum-Wellston area. The Lehew are shallow soils similar to the Muskingum but developed from reddish thin-bedded shales. The reddish tint is apparent throughout the soil and soil material, except in the immediate surface layer which is grayish brown or dark grayish brown to a depth of 3 to 6 inches. Much of the land is stony.

Use.—The use of the lands of this area for cultivated crops is limited by the unfavorable relief and the shallowness and stoniness of the soils, and most of the land is in second-growth timber and brush. Small fields are cropped in corn, garden vegetables, small grains, and hay. Some of the land is in pasture, which, unless improved by fertilization and sowing of the better pasture grasses and clover, is of poor quality.

In this area, as in most rough lands, the soils of the stream bottoms are important out of proportion to their total extent. The better-drained soils of the first bottoms—Pope (fig. 2, p. 1023, Dekalb-Leetonia areas), Moshannon, and Philo, and of the stream terraces—Holston and Monongahela—are generally under cultivation.

Perrine and Rock Land Area

Geographic setting.—This area includes the extreme southern part of the mainland of Florida. The surface is flat to undulating. Elevation ranges from sea level to about 20 feet above. Some of the soils under cultivation have been drained by canals and ditches. Some of the rock land and sands are naturally well to excessively drained.

Climate.—Oceanic; semitropical. Most of the area is normally free from killing frosts. Mean annual precipitation 60 inches. The rainy season is from May to November; the dry season, November to April. Rains are frequently heavy, and hurricanes occur occasionally.

Native vegetation.—Slash pine on sandy areas over limestone; cypress, dwarf cypress, gums, and mangrove trees in swamp areas.

Soils.—Perrine silt loam, locally known as marl land, is high in lime and is light-gray to grayish-yellow or locally grayish-white floury silt loam underlain by a yellowish-gray to grayish-white silt loam which rests anywhere between 18 and 30 inches on oolitic or coralline limestone. Large areas of this soil occur to the east of Homestead and numerous scattered areas elsewhere. There are extensive areas of limestone rock land with a thin covering of fine loose sand; of very shallow Perrine silt loam; areas of mangrove swamp at tide level; and in the vicinity of Redland, small areas of brown or reddish-brown soil a few inches in thickness overlying limestone. There are also areas of Leon fine sand, Blanton fine sand, Plummer fine sand, muck, pet, and swamp. Comparatively large areas of marl land of variable texture occur in Collier County and are used for the production of potatoes and tomatoes.

Use.—Perrine silt loam is the principal soil for the production of winter truck crops, tomatoes, string beans, potatoes, peppers, eggplant, and cabbage. In the vicinity of Redland, Homestead, Florida City, and Coconut Grove, citrus fruits, avocados, and guavas are grown on shallow soils over limestone. In order to use this rock land it is necessary to scarify the surface by breaking up the limestone to a depth of 5 to 8 inches. Locally excavations are made in limestone rock in which to set citrus trees. The outstanding feature of this section is the scattered areas of soil capable of high development and productivity as contrasted to large

areas of rock land or soils inherently low in plant nutrients, underlain by hardpan, so shallow over rock, or so low-lying and poorly drained as to render them unsuitable for farming purposes.

Talladega-Fannin Area

Geographic setting.—The Talladega-Fannin area is a narrow belt of rolling or rough to semimountainous country extending northeast from central Alabama into Georgia. Elevations range from 1,000 to 2,200 feet. The country is rolling to hilly and semimountainous with narrow winding ridges, knolls, steep slopes, and scattered gently rolling areas. Drainage is good to excessive. Streams have cut many narrow V-shaped valleys.

Climate.—Mild, temperate. Short winters; long summers. Mean temperature 61° F. Rainfall 50 inches, well distributed. Frost-free season 200 days.

Native vegetation.—Second-growth shortleaf pine, black, white, post, and scrub oaks, hickory, and ash; original-growth longleaf and shortleaf pine, ash, hickory, and oak. Some revenue is derived from the sale of timber and cross ties.

Parent materials.—Metamorphic rocks including Talladega slate, serritic phyllites, and mica schist. Rocks near surface and outcrops common on steep slopes. Flat particles and fragments of schist and some quartz.

Soils.—Characterized by smooth, greasy or flourlike feel, silty texture, presence of large quantity of small mica scales, and medium to strongly acid reaction. Talladega soils occupy the rougher and more broken areas. The surface soils are brown to light reddish over red to light-red silty clay loam to clay subsoils, firm but brittle, dominantly shallow to bedrock, and contain enough mica to give a greasy feel. The soft disintegrated mica schist and phyllites of variegated colors are reached at depths of 20 to 40 inches below the surface.

The Fannin soils differ essentially from the Talladega in that they are developed on smoother relief and have slightly heavier subsoils. At about 20 or 24 inches the materials become more friable and the underlying soft bedrock is reached at about 40 to 50 inches below the surface.

Associated with these soils are small areas of Chandler soils, with light-gray surface soils, underlain by yellow friable micaceous silty clay loam subsoils, and Louisa soils with red surface soils and red friable micaceous subsoils. Erosion has been very active on these soils.

Use.—Most of the farming operations are conducted on areas having comparatively smooth relief, and corn, cotton, oats, cowpeas, soybeans, potatoes, sweetpotatoes, strawberries, peaches, and garden vegetables are grown. Bermuda grass does well. The present system of farming is not conducive to soil improvement or soil conservation, and has resulted in a meagerly self-sufficing agriculture.

Upshur-Muskingum Area

Geographic setting.—The Upshur-Muskingum area is situated in the western part of the Appalachian Plateau in western West Virginia, northeastern Kentucky, and southeastern Ohio. The relief is broken, consisting of narrow ridges and V-shaped valleys. The strongly sloping hillsides are marked by well-defined successive benches. Elevations range from 400 to 600 feet above sea level along stream bottoms to 1,200 to 1,500 feet along ridge tops.

Climate.—In common with the western Appalachian region the winters are moderately cold, summers hot, and both of about the same length. Average annual precipitation of 40 inches is well distributed throughout the year.

Native vegetation.—Hardwood, consisting mainly of oak, with poplar, hickory, walnut, and locust. About 60 percent is cleared and the rest is a second-growth forest.

Parent materials.—Alternate thin beds of red calcareous and acid shales, and gray shales and sandstones of the upper "Coal Measures."

Soils.—Meigs soil, a complex of Upshur and Muskingum materials, is most extensive. Meigs soils have no definite profile except that of the parent materials. There is, however, some mixing of materials on the steeper slopes. Upshur soils, developed upon red calcareous shales, usually have reddish-brown clay loam surface soils and Indian-red clay subsoils. Muskingum soils, developed from gray shales and sandstone, have grayish-brown silty surface soils over yellow-brown friable subsoils, passing into the partly disintegrated parent material at about 2 feet. These soils are well drained.

The soils upon the terraces consist of: Holston, well drained, gray surface soil, yellow-brown friable subsoil; Vincent, well drained, brown surface soil, red clay subsoil; Monongahela, imperfectly drained, with hardpan or clay subsoil; Tyler, imperfectly to poorly drained, with clay subsoil. Bottom lands consist of: Moshannon and Pope, well drained; Philo, imperfectly drained; and Atkins, poorly drained.

Erosion is active upon the upland, slips and slides probably doing the most damage.

Use.—Used extensively for pasture, containing bluegrass and poverty grass; to a lesser extent for hay, corn, wheat, oats, buckwheat, potatoes, tobacco, and apples. Yields are fairly good. Cattle raising is the leading farm occupation. Relegation of steeper lands to forest, improvement of sod, strip cropping, and better grazing practices are needed in this section.

Undifferentiated Rough Stony Land and Shallow Podzols (Forested)

In the mountainous sections of Maine, New Hampshire, Vermont, and New York, and in the rougher parts of northern Michigan and northern Minnesota are areas which are shown on the map as undifferentiated rough stony land and

FIGURE 42.—Rough stony land, Gloucester material in background.

shallow Podzols (forested). These areas have certain common characteristics, including a rough or mountainous relief, shallow stony soils (fig. 42), which in places show a definite Podzol profile, and native vegetal covering of forest—mostly of conifers. Patches of bare rock are exposed in many places and in some places they occupy a large part of the land. Only a few comparatively small areas—in valleys and on smooth slopes and tablelands—are suitable for cultivation. Grazing for livestock is furnished by grass and brush in some of the cleared areas or in places where the woods are less dense.

Rough Stony Land–Alpine Meadows

In the Rocky Mountains, the Sierra Nevada, and the Cascades, as well as in some of the intermountain ranges, there are areas lying largely above the timber line which consist of a complex of barren rough stony land and alpine meadows. The areas of alpine meadows are most extensive at about the level of or just above the timber line and dwindle in number and size with elevation, giving way to the bare rock of the mountain peaks.

Alpine meadows have a thick growth of grass and flowering herbaceous plants, and are noted for their beauty in midsummer.

The soils are typically shallow and stony. The surface soils are dark brown or dark grayish brown to nearly black, contain much organic matter and have a granular or crumb structure. They seem to have little definite profile development, though it has been noted that orange-colored streaks are common in the subsoil in some areas.

Alpine meadows have fair to good grazing value during the summer, but the grazing season is short. The rough stony land associated with the meadows is barren and practically valueless for grazing.

LITHOSOLS AND SHALLOW SOILS (ARID-SUBHUMID)

This is a group of miscellaneous intrazonal and azonal soils varying greatly in character and degree of soil development, nature and depth of soil and soil material, and in external features of relief, stoniness, and drainage. For the most part, however, these are shallow soils on rough hilly or mountainous terrain. They are stony in many places, and commonly have little soil development and no definite profile. Parent soil materials or underlying bedrock are exposed in many places, though in others there is a fairly well developed soil. Native vegetation is grass in some areas, and in others consists largely of brush or thin open stands of timber. The chief use of the land is for livestock range.

McCammon-Deschutes Areas

Geographic setting.—The McCammon and Deschutes soils occupy juniper-studded mountain ranges and high plateaus of the Great Basin and other parts of the western intermountain region, at elevations of 3,000 to 7,000 feet. They are associated with lower lying areas of Desert soils. The areas are practically uninhabited.

Climate.—Semiarid. Rainfall 10 to 15 inches. Summers dry, rather short, and moderate. Winters long and cold but sunny.

Native vegetation.—Sagebrush and open juniper or juniper-piñon woodland, with a scattered growth of bunch grass.

Parent materials.—Consolidated rocks including basalt, limestone, quartzite, sandstone, and shale, and outwash or colluvial materials from these rocks.

Soils.—These areas have for the most part never been covered by detailed soil surveys. The soils are complex, as they are developed on rough terrain from a variety of parent materials. They are mostly shallow and stony or gravelly and subject to rather rapid natural erosion. The surface soils range from light brown or grayish brown to dark rusty brown or, rarely, red. They are not typically limy where undisturbed. Subsoils are light gray, limy, and more or less cemented. The light-gray limy subsoil is exposed in many places.

Use.—These areas have very little value except as range for livestock, and the carrying capacity is low. Control of grazing would doubtless improve the vegetative cover of the land and help to check run-off and erosion.

Pierre Area

Geographic setting.—The Pierre soils are the dominant soils of a large area in central and western South Dakota and extending into Nebraska, Wyoming, and Montana, at elevations ranging from about 1,800 to more than 4,000 feet. Distinguishing features of these soils are their heavy, sticky nature and their characteristic slate or olive-brown color. Undulating or gently rolling tablelands and wide shallow valleys make up the smoother areas. The breaks toward the streams consist of rather steep rounded hills. Some lands near streams are excessively eroded. Extensive tracts of badlands have been carved in the Pierre soil material.

Climate.—Average annual precipitation ranges from 15 inches in the western part to 20 inches in the eastern part. The mean annual temperature is about 45° F. Average number of days free from killing frost in different parts of area ranges from 120 to 140. Summers are hot and winters cold.

Native vegetation.—Short-grass vegetation predominates. Grama and buffalo grass are dominant on the smooth land. Various grasses and weeds grow on the slopes.

Parent materials.—Cretaceous shales mainly of the Pierre and Graneros formation.

Soils.—The Pierre soils have moderately dark surface soils and dense, clayey or shaly subsoils. The clay, clay loam, and silty clay loam types predominate. The soils are extremely sticky and plastic when wet and hard and tough when dry. The unaltered or partly weathered shale is usually within a depth of 3 feet on smooth areas and nearer the surface or exposed on eroded slopes. Lime may occur in the surface soil and is always abundant at a depth of 18 to 24 inches. On the terraces and flood plains within the area, soils similar in most respects to the Pierre soils are developed. In places cappings of sandy materials over the Pierre shale have produced comparatively small areas of sandy loams or loams.

Use.—In years of ample rainfall the smooth land is very productive. Wheat, oats, and corn are the principal crops. In dry seasons the soil loses moisture rapidly and bakes and cracks badly. The average yields of all crops for this region have been low, because the heavy Pierre soils are not able to absorb the precipitation before it is lost through run-off and evaporation. Much of the smooth land and all the slopes are used only for pasture.

Potter Areas

Geographic setting.—Potter soils are comparatively light-colored, shallow soils occurring on rolling lands of the High Plains of the Texas and Oklahoma Panhandles and southwestern Kansas. The larger areas are shown on the map, but there are small areas in many other sections. They are often associated with rough broken land and with smoother areas of deeper soils of redder or darker color. Elevations range from 1,500 to 3,000 feet above sea level.

Climate.—Warm-temperate and subhumid or semiarid. Summers rather long and hot; winters, mild or moderate and rather short. Annual rainfall ranges from 20 to 30 inches in different localities.

Native vegetation.—Grass, often very thin, though fair on the less eroded areas.

Parent materials.—Deep deposits of chalky calcareous clays, marls, or caliche.

Soils.—Potter soils have grayish-brown, brown, or light-brown surface soils of fine sandy loam to clay loam texture, relatively poor in organic matter, over gray or yellow subsoils grading at a depth of 1 to 2 feet into white chalky carbonate of lime. In places where this chalky substratum lies near the surface the surface soil appears almost white and contains air-hardened fragments of the limy material. These soils have been subject to extensive natural erosion, have a low water-holding capacity and low inherent productivity.

Use.—These soils are useful mainly for grazing. They have little or no value for farm crops.

Underwood-Babb Areas

Geographic setting.—The Underwood, Babb, and associated soils occupy large areas of thinly timbered mountains throughout the interior of the far West, at elevations of 1,000 to 8,000 feet. The relief is rolling to steep, rough and mountainous, and the country is largely uninhabited.

Climate.—Subhumid. Rainfall, 20 to 30 inches. Summers commonly dry with moderate temperatures. Winters long and cold.

Native vegetation.—Open stands of ponderosa pine or Douglas fir with undergrowth of sagebrush and other shrubs, bunch grass, and flowering herbs. In other places there are small, rather dense groves of aspen or lodgepole pine alternating with open areas of sagebrush and grass. South slopes commonly have comparatively little timber, whereas north slopes may be rather densely timbered, and open timber stands characterize the smoother ridge tops.

Parent materials.—A great variety of igneous, sedimentary, and metamorphic rocks, either in place or in the form of talus slopes, outwash fans, or terraces.

Soils.—Only a few small areas of these soils have been mapped by the Soil Survey Division and their characteristics are not known intimately or in detail. They do not exist as large uniform areas but are exceedingly complex. They vary greatly in color, texture, structure, depth, stoniness, and relief in short distances, though they are mostly shallow, stony, and lacking in very definite profile development. On the ridge tops and south slopes the larger areas have brown to dark-brown or nearly black topsoils over lighter brown subsoils. Where the parent materials are calcareous there may be a light gray layer of lime concentration in the lower subsoils, but this is not typical of the larger areas. On north slopes where the timber is heavy, the soils below the dark leaf mull are light brown, leached, and similar to those of the Helmer-Benewah-Santa series.

Use.—The land has value for grazing and timber production, and large areas lie within the national forests. The carrying capacity of the range is much higher than that of the Desert soils but may be somewhat lower than that of the Chernozem and Chestnut soils of the Great Plains. Some small areas have been cleared and are devoted to farming. Wheat, timothy, clover, potatoes, and vegetables are the principal crops, but yields are comparatively low.

Control of grazing and prevention of forest fires are important to conserve the vegetative cover and to minimize erosion.

Valera-Ector Areas

Geographic setting.—The Valera, Ector, and associated soils lie on and occupy the major part of the Edwards Plateau, a large area of rolling to hilly, stony land in west-central Texas. The elevation ranges from 2,000 to 3,000 feet above sea level. The underlying bedrock is hard limestone that has been deeply cut by erosion. Most of the land is in large and small livestock ranches.

Climate.—Warm-temperate and mostly subhumid, but in the western part semiarid. Average annual rainfall ranges from about 15 inches in the west to about 25 inches in the east. It is irregular, and droughts are of rather frequent occurrence. Winters are mild, with average temperature of 40° to 50° F.; summers, long and hot.

Native vegetation.—Chiefly short grasses, including mesquite, buffalo grass, and grama, and a scattered growth of small oak and mesquite trees and shrubs.

Parent materials.—Weathered hard limestone and interbedded chalky marl.

Soils.—Valera soils are dominant in the eastern part of the Edwards Plateau and Ector soils in the western part. They are both shallow, calcareous soils over limestone, the former being brown to dark brown or dark grayish brown, whereas the latter, developed under slightly lower rainfall, is brown, light brown, or light grayish brown in color. Valera soils are largely clays or stony clays, and the fine material is crumbly and fairly mellow and rests either on a thin brown clay subsoil or directly on bedrock. Ector soils are somewhat lighter textured or loamier and very thin. There are large associated areas of rough stony land and small areas of deeper soils. There are some rather large bodies of deep Reagan soils in the northwest part of this section. (See Reagan-Springer areas, p. 1094.)

Use.—The land is mostly nonarable and is used largely for livestock ranching. The varied vegetation, including both grass and shrubs, affords both grazing and browse, and cattle, sheep, and goats are raised and grazed, often on the same land. Cattle are more commonly raised in the eastern sections where, as a rule, grasses are more abundant. Very little farming is attempted, though on some of the deeper soils in the east small acreages of feed crops and cotton are grown. Moisture conditions are such that crops often suffer from drought even on the deeper soils. Ranches range in size from 400 to 5,000 acres in different counties, and most of them furnish a good standard of living to the operators.

It is estimated that about 80 percent of the mohair produced in the United States is from high-grade Angora goats of the Edwards Plateau, and, therefore, almost entirely on these soils.

LITHOSOLS AND SHALLOW SOILS (RELATIVELY SPARSE VEGETATION)

In the arid West there are large areas of shallow, stony soils and rock outcrop, usually in rough or more or less mountainous country. The soils are varied, their character depending largely on the nature of the underlying rock. They are, in many places, highly calcareous. The land has value chiefly as range for livestock, though in places it has scenic and recreational value. This group includes rough stony land (not forested), rough broken land, and lava beds.

Rough Stony Land (Not Forested)

Throughout the western mountains are areas of steep, rough, stony land which have little or no timber cover and little other vegetation. In the Southwest such areas are common and extensive. Here the long, narrow, parallel desert ranges consist of nearly bare rock with a scant growth of creosote bush, cactus, and other

desert shrubs. There are included in this class many rock-walled canyons such as the Grand Canyon of the Colorado and the Snake River Canyon.

The land has in most places no value for agriculture and only small value for range. Sheep and goats are able to get over the surface in many places and obtain some browse or grass. A few narrow strips of land in canyon bottoms are farmed and are producing fruits, vegetables, alfalfa hay, and small grains. These sometimes form the nucleuses for cattle ranches. The country has scenic interest and recreational value and contributes to the water supply of the region.

On the plains of western Texas, especially on the Ewards Plateau, rough, eroded, stony areas are mapped as rough stony land. They have much grass in places and scattered brush and small trees, and have a relatively high value as grazing land. The same applies to smaller areas in Oklahoma, Texas, New Mexico, Arizona, and California, which are not shown separately on the soil map of the United States.

Rough Broken Land

"Rough broken land" is a term applied to tracts consisting largely of steep or rough eroded land, less stony than rough stony land. It consists largely of so-called badlands—barren, excessively eroded areas with little soil development (fig. 41). Swiftly flowing waters have broken down the soft rocks and cut gullies and gorges with steep slopes. Over areas of many square miles the eroded slopes spread to cover the entire surface, and the original plain is broken up. In other places, remnants of the original surface are left standing as tables or buttes above the dissected waste, or a considerable part of the surface, although escaping destruction, may be traversed and isolated by badland areas.

Rough broken land is extensively developed over the clays and soft shales of the Tertiary formations in the northern part of the Great Plains and over clays and sandy shales of the "Red Beds" formations in the southern part. Long, comparatively narrow strips of such land mark the escarpment of the High Plains in Texas and Oklahoma.

Though a large part of the land is practically devoid of vegetation, patches of unbroken plain that have escaped denudation, occasional gentle alluvial-fan slopes and narrow flood plains in the floors of canyons support a growth of grasses, shrubs, and occasional trees that furnish grazing and browse for livestock. Stockmen also value the land for the bluffs and valleys which shelter animals from the winter storms.

Lava Beds

In parts of the western intermountain region, notably in southern Idaho and eastern Washington, there are large areas of comparatively recent lava (basalt) flows which have an uneven surface and little or no covering of soil. Such areas are commonly called scabland. In places, as in the Craters of the Moon National Monument in southern Idaho, large areas of rock are absolutely bare, whereas in other places only the higher wavelike ridges are bare and the hollows between them are filled with soil. In places the surface is covered by volcanic cinders, and cinders and fragments of pumice are scattered through the soil material.

These areas are in arid or semiarid country and the characteristic vegetation, where there is sufficient soil to support it, consists of sagebrush. In places there are scattered pine or juniper trees and a thin growth of bunch grass.

The scabland areas have little value except as range for livestock, and the grazing value is low. In places, very small included areas of soil are farmed, largely under irrigation, and alfalfa, small grains, potatoes, sugar beets, and vegetables are grown. Dry-farmed areas produce only wheat.

BOG SOILS

The Bog soils are represented by two general groups—peat and muck, and coastal marshland. They are poorly drained soils consisting of or developed from accumulation of plant remains.

Peat and Muck

Peat and muck cover a total area in the United States estimated at 79,000,000 acres. They exist under a wide range of climate and vegetation, but the most

extensive areas are in the Southeast, the Great Lakes States, and the Pacific coast region. On the soil map of the United States a few of the most important areas are shown. The smaller bodies are included with closely associated mineral soils.

Peat and muck have developed from the vegetation of marshes, bogs, and swamp forests (fig. 43). Each has contributed plant remains accumulated either in basins

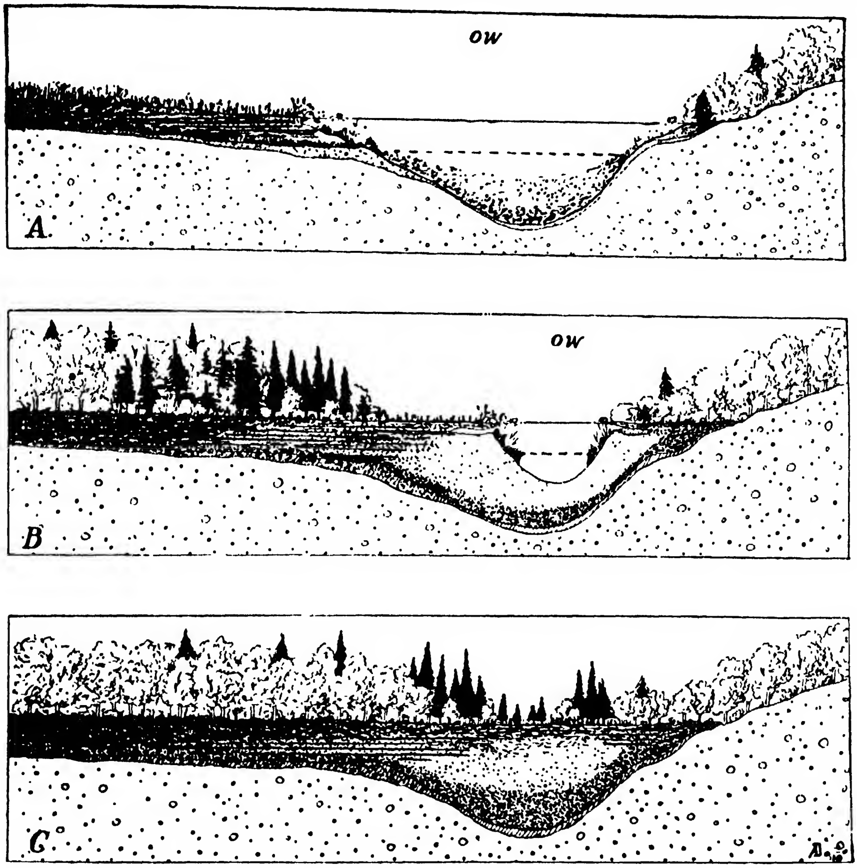


Figure 43.—Diagram illustrating vegetation units, their general succession, and the influence each has in the origin, formation, and history of peat land. Peat-forming plant associations displace one another through three major stages and give rise to a sequence of different layers of peat, representing aquatic, marsh, and swamp-forest vegetation that contribute to the formation of sedimentary, fibrous, and woody peat, respectively. *A*, Accumulation of aquatic vegetation in open water (ow) bordered by marsh vegetation (on the left). *B*, Filling in of the open water by plant debris and closing in of marsh vegetation. *C*, The swamp forest has taken the place of both aquatic and marsh vegetation.

of standing water or on land with a rising water level. These materials characterize the profiles of areas of peat and muck, usually as a sequence of layers in various arrangements.

Peat is an organic material consisting of an accumulation of plant remains in varying degrees of preservation or decomposition. There are three principal classes of peat—sedimentary, fibrous, and woody—each with distinct physical and chemical properties.

Muck is the product of decomposition of peat and consists of organic residues that are more or less mineralized. Physically it is a very dark brown or black granular material, and chemically it is a mixture of complex substances varying with the parent peat material and climate.

Areas of peat and muck present many land-use problems, among which are those connected with market gardening, farming, wildlife preservation, water conservation, control of floods and erosion, and use as sources of organic matter for soil improvement. Their suitability for special crops such as onions and celery, or for grain-and-stock farming, depends upon the character of the surface material, profile, mineral substratum, and ground-water conditions.

Illustrations and descriptions of different types of peat and muck in this country are contained in a number of publications of the United States Department of Agriculture and in articles in scientific periodicals (*86*, *87*, *88*).

In the following pages several of the important areas of peat and muck in different geographic regions are discussed briefly.

Northern Areas

Geographic setting and climate.—Northern areas of peat and muck are in a cool-temperate, humid region extending from northeastern Maine and northwestern New Jersey to Minnesota and Illinois and in other areas of somewhat similar climate in northern Idaho and northern and western Washington. Peat and muck occur on pitted plains, in stream valleys, and along borders of lakes and ponds.

Native vegetation.—Swamp forests of spruce, tamarack, and arborvitae in the north, and various conifers, maple, elm, and ash farther south; reed and sedge marshes; and sphagnum moss and heath bogs.

Soils.—In Maine raised bogs are common. A typical profile of a raised bog of Denbo peat consists of: (1) An upper layer of yellowish brown, poorly decomposed, strongly acid, spongy-fibrous moss peat, about 4 to 6 feet thick; overlying (2) a dark-brown layer of acid woody peat 1 or 2 feet thick, containing logs, stumps, litter, and woody fragments from conifers; and (3) a basal layer of brown fibrous peat derived from thin roots and underground stems of sedges and grasses common to marshes. It is 3 to 4 feet thick and moderately acid. The underlying material consists of plastic organic sediments that accumulated from aquatic plants in shallow water over sand, clay, or bedrock.

Farther south the surface materials are mostly from reeds, sedges, conifers, maple, ash, and elm. Better drainage conditions and warmer climate have developed mellow friable muck, well decomposed, slightly acid or neutral in reaction, and undergoing mineralization. Various types such as Rifle peat and Carlisle muck have been recognized in this section and their characteristics and value in relation to crops have been described, notably in reports of the Soil Survey Division of areas in Michigan.

Use.—The various types of peat located in the cooler sections are not regarded as especially favorable for crops. They have not reached the advanced stage of decomposition of peat land farther south, and are subject to late and early frost. Pasture grasses and hay and, in places, corn and potatoes can be grown on woody peat and fibrous sedge peat where the danger from frost is least and drainage is well controlled. Most of the timbered areas are of value for tree growth and as a refuge for wildlife. Some of the dome-shaped types of moss peat might be selected for commercial uses in the preparation of stable bedding, poultry litter, and organic matter for soil improvement. The United States imports most of its moss peat, principally from Europe.

Types of dark-brown or black granular muck have produced large quantities of vegetable crops; agriculture is much better developed, and in many places grain-and-stock farming provide a good distribution of labor throughout the year. The use of fertilizer, especially potash, is profitable, and rotations with oats and rye are common when the principal crops, such as onions, celery, and cabbage are threatened with insect pests and plant diseases. The domestic production of reed and sedge peat and much for soil improvement has attained commercial importance in this area.

Southeastern Coastal Plain Areas

Geographic setting.—Extensive areas of woody and fibrous peat and muck occur in the flat seaward part of the southeastern Atlantic Coastal Plain. They occupy

level upland terraces, generally of Pamlico age, and border practically all lakes, ponds, and streams near sea level.

Climate.—The region has an abundance of rainfall which causes a loss of bases from the soil, and a relatively high temperature that favors decomposition.

Native vegetation.—Mainly swamp forests of cypress-tupelo-gum, and canebrakes.

Soils.—The woody peat is generally dark brown in color, moderately well decomposed, and strongly acid in reaction; it contains buried logs and stumps and has been built up on level sandy plains from a succession of two or three different forests dominated by cypress or white cedar and by mixtures with gum and red maple.

The most common types of the fibrous peat are derived from underground stems and roots of dense stands of cane, sedges, rushes, and grasses accumulated in water basins or on land with a rising water table. There are also large areas of woody-fibrous peat, known as pocosins, which developed from a mixed open growth of canes and sedges interspersed with bay shrubs, gallberry, and myrtle. In many of these peat areas the content of plastic colloidal material is comparatively high and appears to be a factor in retarding the growth of crops.

Use.—There is little agricultural development and little probability of much expansion in the near future. Growing of timber and the preservation of wildlife are among the more profitable uses for peat and muck in this region. In areas like the Dismal Swamp of Virginia and Okefenokee Swamp in Georgia, the layers of woody peat with their vegetation cover tended to retard the flow of surface waters and impounded rainfall into reservoirs of stored water of which Lake Drummond is a striking example. Both the Dismal Swamp and Okefenokee Swamp should be conserved as national parks and wildlife sanctuaries.

Everglades and Related Areas

Geographic setting.—Peat and muck areas in the warm and humid Gulf Coastal Plain are represented typically by the Everglades of Florida. This area is the largest among many similar marshes of which some are filled water basins, and some border lakes, ponds, and wooded streams, whereas others are accumulations built up on sandy plains or, as in the case of the Everglades, on bedrock near sea level.

Climate.—Subtropical and humid. Rainfall heavy.

Native vegetation.—Peat-forming plant communities grow luxuriantly; the marshes are characterized by tall sedges, grasses, and rushes; the swamp forests by cypress, tupelo, and other trees.

Soils.—Several distinct types of peat and muck have developed in the marshes:

(1) Muck, developed from black organic sediments from aquatic vegetation, occurs within a narrow belt bordering the southern shore of Lake Okeechobee. It contains some silt and clay, is dense and sticky when wet but shrinks and becomes quite hard when dry, develops surface cracks with angular fracture and crumbles into a granular mass. Practically all of the Okeechobee muck is underlain by brown fibrous sedge peat resting on bedrock.

(2) Brown or dark-brown partly decomposed fibrous sedge peat occupies most of the extensive Everglades; it consists of fine roots and flattened coarse underground stems of, dominantly, sawgrass. In the outer border of the area profile sections show fibrous, porous material, but in the interior part of the Everglades a black pasty sedimentary layer occurs below the surface that is relatively impermeable to roots of plants, air, and water. It is underlain by brown or dark-brown fibrous sedge peat that rests on limestone rock.

Use.—The Okeechobee muck is used for the production of sugarcane and vegetables such as onions, cabbage, tomatoes, peppers, and beans. Comparatively little use has as yet been made of the peat of the Everglades or of the associated peaty muck phases, shallow marly phases, and the gray granular marl developed mainly from algae. Some drained areas have been planted to vegetables, sugarcane, and peanuts; but several limiting factors, among them nutrient deficiencies, hazards of frost, frequent surface and underground fires, and shallow depth to bedrock, have contributed to uncertainty of the economic usefulness of a large acreage in the Everglades.

Throughout many centuries the layers of peat built up on bedrock along the northern border of the Everglades impounded the waters from the Kissimmee River Basin, gradually giving rise to Lake Okeechobee. Consideration should

be given to the desirability of utilizing the greater part of the Everglades as a semitropical national park and wildlife reserve, and for conservation of water supplies and replenishing the flow of artesian wells.

Pacific Coastal Valley Areas

Geographic setting.—In the semiarid Pacific valleys, peat and muck are developed extensively in the tule marshes of the Klamath Plateau of northern California and southern Oregon and in the delta peat land at the confluence of the San Joaquin and Sacramento Rivers about 50 miles inland from San Francisco.

Climate.—Low rainfall and dry, hot summers with high evaporation, favoring a marked accumulation of soluble salts.

Native vegetation.—Mostly tules, reeds, sedges, rushes, and aquatic plants.

Soils.—Klamath tule peat is characterized by brown fibrous, porous, and poorly decomposed plant remains. The material underneath the surface consists of gray fine organic sediments, principally silicious shells of diatoms, with an admixture of volcanic ash.

The Sacramento-San Joaquin delta area consists of a number of peat islands which supported originally a dense growth of tule, reeds, and aquatic plants. Most of the islands developed in open water and represent lake-filled types of considerable thickness; others accumulated on flat land and were built up under conditions of a rising water table. Several types of peat and muck have been distinguished in the reports of the Soil Survey Division of areas in California and in other publications.

Use.—Drained areas under cultivation and irrigation in the Klamath district produce at first good yields of alsike clover, rye, barley, and tame grasses, but the yields soon decline when evaporation lowers the ground-water level and salts in injurious quantities begin to accumulate at the surface. Consideration should be given to the need of conserving water for irrigation during periods of low rainfall, and to the possibility of restoring lower Klamath Lake to its former condition for storing water supplies and as a migratory-bird refuge.

The islands of the delta district are now under cultivation and protected from overflow by levees. The surface materials and their relationships to crops may be listed as follows: (1) Yellowish-brown, coarsely fibrous, porous reed peat, commonly known as buckskin peat, not used successfully for profitable agricultural crops under present conditions; (2) reddish-brown fibrous tule-reed peat, generally fertile and productive for potatoes, sugar beets, asparagus, onions, and other intensively grown crops; and (3) dark-brown sedimentary and sedimentary-fibrous peat, comparatively dense and offering some difficulty in drainage and tillage but usually productive where properly managed.

In the virgin condition the surface elevation of the peat islands was approximately at sea level. Since reclamation the surface of most of the islands has been gradually subsiding and in some places cultural practices have lowered the present level 8 or 10 feet below sea level. Many uncertainties have arisen as to the probable effects on agricultural activities in this area and as to what proportion of the islands can be used for other purposes.

Coastal Marshland

Geographic setting.—Coastal marshland occurs in scattered areas in tidal channels at the mouths of rivers which empty into the ocean, in quiet waters of lagoons, and behind barrier islands which fringe the coast. The most important areas are along the Gulf and Atlantic coasts. Many areas are too small to be shown on the map.

Climate.—High rainfall during the summer season; prevailing coast winds from the relatively cool ocean waters accentuate the wetness of the growing period.

Native vegetation.—A dense growth of saltgrass, sedges, herbaceous plants, and shrubs. In semitropical regions, notably on the southern shores of Florida, the mangrove, a shrubby evergreen tree, predominates.

Soils.—Several types of peat develop from each form of vegetation, each with distinct characteristics and suitability to crops and other uses. Generally the surface materials consist of yellowish to reddish-brown, coarse, fibrous and matted peat, porous and permeable, gradually built up over black clayey mud flats or gray loose sand by accumulation of plant remains. Gradations from salt-water to brackish and fresh-water types are frequently encountered.

Vegetation in areas subject to high tides and wave action or river currents retards the silt-laden overflow. The mineral material mingles with the mass of roots, tending to form various clayey and silty phases. The surface material is accordingly more or less compact, impermeable, and plastic, bluish gray in color, mottled with iron stains, and may be underlain by fibrous peat containing hydrogen sulphide.

Use.—Experience, both in this country and abroad, has shown that types of coastal marshland, when drained and used for hay or grain crops including rice, undergo decomposition and a long-continued shrinkage. The amount of subsidence varies with the depth and character of material. Ditches become more and more ineffective and further drainage can be accomplished only through an ever-increased use of pumps and dikes.

In its natural condition, coastal marshland offers food and nesting places for migratory game birds, waterfowl, and other wildlife. In areas adjacent to seashore resorts, consideration should be given to the problem of preventing mosquito breeding without altering greatly the native vegetation harboring wildlife.

FIGURE 44.—Hay and corn on Huntington silt loam near Clarksville, Tenn. This soil is rightly considered one of the best agricultural soils in localities in which it occurs. It is used mainly for the production of corn and hay.

ALLUVIAL SOILS

Alluvial soils occur in all parts of the United States, on flood plains, first bottoms, or low terraces along streams. In some of the mountainous sections there are alluvial soils on the more recent alluvial fans or so-called colluvial slopes. Only the larger areas are shown on the soil map of the United States at the end of this volume. Other smaller areas, not shown on the map, are scattered throughout the country. The term "alluvial soils" applies only to the more recently deposited water-laid materials, which have been very little changed by the environment. Their characteristics are determined largely by the nature of the materials from which they have been derived and the manner in which these materials have been sorted and deposited. The climatic conditions, drainage, and vegetation vary widely.

Many of the most productive soils of the world are alluvial soils, though many areas are subject to disastrous floods, and others, because of poor drainage or accumulation of salts or a combination of these factors, are unproductive or unsuited to cultivation.

Northeastern Alluvial Soil Areas

Few alluvial soil areas of the northeasern United States are extensive enough to be shown separately upon the soil map though they are important agriculturally. Among the more important soil series of the region are the Huntington, Genesee, Tioga, Ondawa, Hadley, and Pope (figs. 44 and 45). They come from a wide variety of materials, range from acid to neutral or slightly alkaline in reaction, are mostly brown or grayish brown in color, have a mellow consistence, and are fairly or highly productive where well drained and protected from overflow. Though relatively inextensive they constitute an important element in the agriculture of the regions where they occur. Small areas of alluvial soils may be used for producing intensively cultivated crops, in connection with larger areas of uplands used for pasture and timber. Corn and hay are the principal crops. Vegetables are important in places. Poorly drained lands are used largely for pasture.

FIGURE 45.—Corn for silage on Agawam fine sandy loam, a soil of alluvial origin near Springfield, Mass.

Southern Alluvial Soil Areas

The largest area of alluvial soils in the United States is along the Mississippi River below the mouth of the Ohio. Other large southern areas are along the Pee Dee, Santee, Altamaha, Trinity, Brazos, Colorado, Red, Ouachita, and Arkansas Rivers. There are many smaller areas throughout the South, too small to be shown on the soil map. These soils occupy mainly first bottoms and low second bottoms and are subject to rather frequent and heavy overflow. They are almost flat, and drainage ranges from fairly good to poor. The land, where uncleared, has a covering of oaks, hickory, gums, beech, ash, cypress, holly, ironwood, cottonwood, and pine.

These soils come from a great variety of soil materials. They are, for the most part, inherently fertile, and where drained and protected from overflow are highly productive. There is a range of soil texture from sand to clay. The alluvial soils of the lower Mississippi Valley, the limestone valleys, and the Piedmont Plateau are commonly of finer texture and more fertile than the soils of the Coastal Plains. Among the more important soils of the Mississippi flood plain are the Sharkey, Sarpy, and Yazoo soils. Other important soils of the region are Congaree, Wehadkee, Altamaha, Ocklockonee, Hannahatchee, Bibb, Trinity, Catalpa, Osage, Verdigris, Arkansas, Frio, and Blanco.

Cotton and corn are the most important crops on these soils. Cotton is the chief crop on the Mississippi Delta, and large yields are obtained without fertiliza-

tion. Other important crops of the alluvial soils of this region are hay, sugar-cane, rice, sorghums, soybeans, cowpeas, and truck crops. Poorly drained areas are in forest or pasture.

Alluvial Soils of the Prairies and the Eastern Great Plains

The alluvial soils of the Prairie and Chernozem belts are developed over sediments mainly derived by erosion from the dark-colored upland soils. Except in areas where drainage is exceptionally poor, these soils retain many of the characteristics of the parent materials. The most widely distributed soils are those of the Wabash series. The surface soils of this series are black and usually thicker than those of the surrounding upland soils; the subsoils are gray or mottled gray and brown with heavy textures. No free lime is present in soil or subsoil. Soils of similar character, except that they contain lime, are placed with the Lamoure series. The Cass soils have dark-colored surface layers, underlain at a depth of 1 to 2 feet by sand or gravel. In places, streams have cut deeply into light-colored materials and redeposited them in the lower bottoms. The light-colored Sarpy soil is underlain by sand or gravel. The Genesee surface soils are similar to those of the Sarpy but have heavier subsoils. The materials that make up the Laurel soils are derived from the western part of the Great Plains and have a higher salt content. Numerous soils of minor importance are the product of local differences of parent materials and of soil-forming conditions.

Corn is the principal crop on the better drained, alluvial soils of the Middle West. Small grains are of minor importance. On some local areas, especially on the ligher soils, melons and other truck crops are grown. Poorly drained land is used largely for the production of hay and pasture.

Alluvial Soil Areas of the Arid West

The alluvial soils of the arid West are on bottom lands, flood plains, low terraces, and gently sloping alluvial fans throughout the western Great Plains and western intermountain region from Canada to Mexico. The largest areas are in the central (Sacramento–San Joaquin) valley of California, the delta and bottom lands of the lower Colorado River and its tributaries in California and Arizona, along the Rio Grande in New Mexico and Texas, and along the Arkansas, Platte, Yellowstone, Missouri, and Milk Rivers on the western Great Plains. The climate is arid or semiarid and ranges from subtropical in the South to cool-temperate in the North. The vegetation is largely of scattered brush in the drier situations and grasses, sedges, willows, and cottonwoods in comparatively moist or poorly drained areas.

Parent soil materials are extremely varied and in many places are distinctly calcareous. The soils are mostly light-colored and rather poor in organic matter, but generally rich in lime and mineral plant nutrients. In places, especially in poorly drained areas, they contain high concentrations of soluble salts ("alkali"). They are irregularly stratified and extremely variable in texture and consistency, ranging from sand to clay and from loose to tough. Some small areas are stony or gravelly. Wet areas with heavy vegetation have dark-colored surface soils and mottled gray, green, and rusty-brown subsoils. Representative soils of the region are those of the Gila, Hanford, Yolo, Pima, Cajon, Imperial, Holtville, Tujunga, Logan, Onyx, Pecos, Rio Grande, Havre, Billings, and Laurel series.

These soils are largely too dry for farming except where irrigated, though a few naturally wet lands produce grasses and sedges used for pasture and hay. The better drained irrigated areas are highly productive of a wide variety of crops. Alfalfa is the most important crop in most places. Cotton, winter vegetable crops, and subtropical fruits are important in the warmer districts of the Southwest; small grains, potatoes, sugar beets, and beans are important farther north. Salty and alkali areas are mostly of little value unless drained and thoroughly leached. Unirrigated lands have some value for livestock range.

SANDS (DRY)

Sands have accumulated in large areas in the semiarid and arid regions through transportation and deposition by the wind. A comparatively small proportion of the land is covered by drifting sand; most of it has a covering of vegetation and the surface has been stationary for many years. On all of them drifting may begin at any time, however, if the surface is disturbed. The instability of these soils is

due to the high winds of the region and to the scanty vegetation, which in many of the areas is not sufficient to bind and protect them from removal by the wind. The sand areas are not planted to cultivated crops but are extensively used for pasture.

Valentine-Nueces-Dune Sand Areas

Geographic setting.—Dune sand, Valentine sand, and similar or associated soils occupy a large area in central and western Nebraska, called the sand-hill section. Similar loose sandy soils lie in smaller areas in North Dakota, South Dakota, and Colorado. On the Coastal Plain of southern Texas an area is covered largely by Nueces fine sand and dune sand. Dune-sand areas are characterized by a monotonous succession of dune hills and ridges with occasional intervening valleys, pockets, and swales, many of which include grassy meadows. There are very few natural surface drainage outlets, but rainfall is as a rule quickly absorbed by the porous sand. Most of the dune sand is covered by grass sod and thus kept from blowing, but there are occasional blow-outs where the grass cover has been removed. Valentine sand is less strongly rolling and has a slightly darker surface layer. Nueces fine sand has a comparatively level surface with some small duny areas.

FIGURE 46.—Sand dunes between El Centro, Calif., and Yuma, Ariz.

Climate.—Average annual precipitation in the Nebraska sand-hill section ranges from 16 to 25 inches. Mean annual temperature is about 47°. Average frost-free season is about 140 days. The wind velocity is high. In the area in southern Texas, the climate is semitropical and subhumid. The average frost-free season is about 300 days. Average annual rainfall ranges from 20 to 25 inches.

Native vegetation.—A great number of species of short and tall grasses.

Parent materials.—In Nebraska, wind-blown sands released by disintegration of Tertiary sandstones. In Texas, wind-blown sandy beach deposits over Pleistocene clays.

Soils.—Dune sand consists of incoherent fine to medium sand. Locally decayed grass remains have slightly darkened the surface to a depth of 1 or 2 inches. Over the greater part of the area, however, dune sand is uniform in texture and consistence and shows little or no change in color from the surface downward. The color of the sand is light grayish-brown. The material is thoroughly leached of lime and other soluble constituents. Valentine sand has a more gently rolling surface and a dense grass cover, and in consequence greater stability. Nueces fine sand is a gray loose fine sand to an average depth of about 3 feet, overlying a slightly mottled gray stiff clay.

Use.—Dune sand and Valentine sand areas are used for the production of livestock under a system by which the animals are grazed on the land during the sum-

mer months and during the winter are fed hay cut on the meadows. The loose nature of the sand and the high velocity of the winds make it unwise to plow the land and destroy the grass cover. The soils of meadows of the sandy areas consist of the heavier types of the Valentine and Gannet series. These soils have accumulated organic matter and support a more or less luxuriant cover of grasses depending on the moisture supply. The Neuces soils are used mainly for pasture, but small areas are used for cotton and truck crops.

Dune Sand

Dune sand in the arid western intermountain region consists of deep deposits of loose sand, in many places forming high dunes (fig. 46). The surface is largely bare, though in places there is a scattered growth of brush, coarse bunch grass and dock, and the land has some small value as livestock range. It is mostly unsuited to agricultural development because of its looseness, low moisture-holding capacity, lack of fertility, and unfavorable topography.

SOILS OF PUERTO RICO AND THE VIRGIN ISLANDS

Climate and vegetation and rock formations vary markedly in short distances in Puerto Rico and the Virgin Islands, and these variations have caused the development of an intricate soil pattern. These islands lie in the belt of the trade winds and have a tropical climate and great variation in rainfall. Highest rainfall occurs in the high mountains which extend across the south-central part of Puerto Rico from east to west. North of this belt it decreases considerably, but in most of the area is well over 50 inches. South of the mountains, from the central part of the island westward, rainfall rapidly decreases and is less than 35 inches in many parts of the south coast. Owing to rapid evaporation, characteristic of the warm trade-wind belt, 35 inches of rainfall here is probably about as effective as 15 inches on the northern Great Plains of the United States. Soil differences in Puerto Rico and the Virgin Islands correspond to a marked degree to the climatic differences.

The Virgin Islands and Culebra and Vieques Islands are off the eastern coast of Puerto Rico. The principal islands of the Virgin group are St. Thomas, St. Johns, and St. Croix. Mona Island is in the Mona Passage west of Puerto Rico. The climate is arid to subhumid. The soils are discussed under the Soller-Aguilita and Descalabrado-Guayama areas (p. 1145).

The Red and Yellow Podzolic soils of Puerto Rico are similar to those of the southeastern United States. The Yellowish-Brown and Reddish-Brown Lateritic soils do not have exact counterparts in the United States. The Laterites (Rosario-Nipe) are of the ferruginous (iron-bearing) type, containing as high as 60 percent of ferric oxide. Some of the soils grouped as Reddish Chestnut soils and Planosols include soils approaching Chernozems in character as well as some that are more similar to the Reddish Chestnut soils of southwestern United States. The Ponceña-Coamo and Santa Isabel-Paso Seco areas include much Planosol and some Solonetz, most of them having more or less strongly developed claypans. Rendzina soils, occurring on soft limestones in both humid and semiarid parts of the island, are mostly too shallow to be of great value for agriculture, though they and the Lithosols and shallow soils, which are very stony in many places, are widely used for subsistence crops in the humid areas and for pasture in subhumid parts.

The alluvial soils are the richest and most productive of the island and produce high yields of sugarcane wherever the water supply is sufficient. Some of the highest yields are obtained on the dry side of the island where water can be obtained for irrigation. Yields are also increased by irrigating alluvial soils on the more humid north side where the rainfall reaches 60 or 80 inches a year. Bog soils of Puerto Rico have a very limited agricultural value because most of them lie at or below sea level and must be pumped dry if they are to be used for ordinary cultivated crops. The undrained areas produce mangroves from which charcoal is made and sold for fuel.

Commercial agriculture includes the production of sugarcane, tobacco, coffee, and citrus fruits, and these crops occupy by far the greater part of the best land of the island. Because of population pressure subsistence farmers have been driven to the poorer lands to develop their farms, and a large total area of the extremely steep land covered by shallow soils furnishes a meager living for the people.

Los Guineos-Catalina-Alonso Areas

[Red and Yellow Podzolic Soils (Lateritic Materials)]

Geographic setting.—The Catalina, Alonso, and Los Guineos soils occur in one of the largest soil belts in Puerto Rico—mostly in the humid uplands of the interior. This area is characterized by steep soil-covered slopes, A-shaped and somewhat rounded ridges, and V-shaped ravines that gradually change toward the coastal plains and interior valleys to gently rolling hills and sloping ravines. The entire area has been deeply cut by streams, and many of the divides are separated by gorgelike valleys ranging from 500 to 1,000 feet deep.

Agriculturally the area is characterized by small fields of sugarcane, pineapples, and grapefruit growing on the lower undulating or slightly rolling land; oranges, bananas, and coffee on the steeper slopes of the higher elevations; and grass and forest on the rugged, jagged, rocky, mountain slopes at the highest elevations. The elevations range from 40 feet near the coast to 4,398 feet, the highest point on the island.

Figure 47.—Twilight at midday in the nearly impenetrable rain forest of the Caribbean National Forest. High mean annual temperature and heavy rainfall make an ideal condition for a rank and varied vegetation, including tall trees, large-leaved shrubs, and thickly carpeted forest floor of ferns, grasses, mosses, and bromeliads.

Climate.—Humid. Mean annual rainfall ranges from about 76 inches along the northern coast to more than 160 inches in the rain forest of the Luquillo Mountains (fig. 47). Rainfall in high elevations fairly evenly distributed; generally there is some rain every day. In the lower elevations most of the rain falls during the summer and fall months. Winter rains, gentle; summer rains, often torrential. Higher parts of this area are the coolest of the island; temperature ranges from 40° F. during coldest winter nights to 98° during summer days. Skies clear at some time almost every day.

Present vegetation.—Mesophytic, rain-forest, or mossy vegetation, depending upon elevation and rainfall. Nearly every cultivated crop grown on the island is produced within this area.

Parent materials.—Tuffaceous rocks, shale (composed largely of volcanic ash) conglomerates, and andesites, all of which weather rapidly under hot humid, climate, forming deep soils that are leached of most of their bases and other plant nutrients.

Soils.—Catalina soils are brownish red or red, Alonso soils are purple, and Los Guineos soils are yellowish red or light brownish red. All of these soils are well drained, fairly permeable, acid, faintly granular clays or silty clays. The material differs but slightly from the surface to the underlying parent rock which occurs at a depth ranging from 3 to 40 feet. The depth to rock usually increases with increasing annual rainfall and with the gentleness of the slopes.

When these soils are cultivated they readily form a good seedbed, even on very steep slopes. They are very permeable owing to the high iron and aluminum and low silicic acid content and are not susceptible to erosion on ordinary slopes of 10 or 15 percent. Steep cultivated slopes erode to a considerable extent. The climate is nearly ideal for exceedingly fast plant growth, and this probably is the greatest factor in keeping erosion at a minimum. Then too, soil development is rapid and tends to balance erosion in some places.

Use.—Physically these soils are adapted to many crops, but, owing to a deficiency in plant nutrients, such as lime, phosphorous, and magnesium, caused by leaching of these necessary elements by the high rainfall, and to rough relief, high elevation, and in many places long distance from towns or roads, coffee, oranges, bananas, and timber are the most important products grown. Many thousands of people will have to depend upon these soils for a portion of their future livelihood, and it is of the utmost importance that the necessary deficient plant nutrients be added so that the soil will be more productive and the products will have a higher nutritive value.

Sabana Seca-Lares Areas

[Red and Yellow Podzolic Soils (Lateritic Materials)]

Geographic setting.—The Sabana Seca, Lares, and similar or associated soils are confined to long narrow terraces or terracelike areas throughout Puerto Rico. They are characterized by level or undulating relief and dotted with numerous small subsistence farms and a few large coffee and sugarcane fincas (individually owned farms). Most of the land has numerous deeply entrenched stream channels and adequate surface drainage, but internal drainage of the soils is restricted. The elevation ranges from 50 to 1,500 feet above sea level.

Climate.—Tropical and humid or subhumid. Mean annual rainfall ranges from 45 inches near Lajas to 110 inches near Lares. Some areas are irrigated.

Present vegetation.—Nearly the entire area cleared and planted (fig. 48) to subsistence crops, sugarcane, coffee, and tobacco, with pasture grass used in the rotation.

Parent materials.—The Sabana Seca soils are mostly on coastal-plain deposits and the Lares soils on acid tuffaceous material washed from nearby hills.

Soils.—The soils in this area have a variety of soil characteristics, depending upon age, parent material, internal drainage, and rainfall. The Sabana Seca soils have a brown or grayish-brown plastic acid surface soil about 6 inches thick underlain by a yellowish-brown plastic acid layer that changes abruptly at a depth of about 10 inches to a very compact, stiff, acid, mottled-brown, gray, and red subsoil that changes but slightly to depths of 6 feet and below. The Lares soils differ from the Sabana Seca in that they have a less heavy subsoil and are slightly red in the surface soil. These soils, especially the Sabana Seca, are closely associated with the Corozo soils, which have a nearly white, sandy, very acid surface soil 8 or 10 inches thick underlain by a thin, nearly black, acid organic hardpan layer 2 or 3 inches thick, grading into a mottled gray and reddish-brown sandy clay layer. All these soils have slow internal drainage. Rains penetrate the surface soil fairly readily but flow laterally on top of the nearly impervious subsoil.

Use.—These soils need artificial drainage to make them suitable for crop production. Owing to the heavy, nearly impervious subsoils they are not well adapted to deep-rooted crops. They are fairly well adapted to subsistence crops, but, as they are low in bases and strongly acid, it is essential to use considerable fertilizer or lime or both. The Lares soils are the most productive and the Corozo the least productive. Many areas of the Corozo soils are idle or in brush.

FIGURE 48.—Landscape in Sabana Seca-Lares area. Pineapples are sensitive to lime, as can be seen by the chlorotic condition of the leaves of those growing on a small patch of a shallow limy Santa Clara soil. The healthy pineapples and grapefruit are growing on the Lares soils; the rounded, smooth, grass-covered hills are Colinas clay loam; and the steep brush-covered hills in the distance are Tanama stony clay.

Coto-Bayamón Areas

[Yellowish-Brown and Reddish-Brown Lateritic Soils]

Geographic setting.—The Coto-Bayamón soil areas include the large coastal limestone belt along the northwestern part of Puerto Rico. They are characterized by thousands of houses built on the fairly productive reddish and yellowish soils of the streamless, gently undulating valleys and by few houses on the shallow red and dark-brown soils of the rugged, bush-covered "haystack" hills (fig. 49).

Climate.—Eastern and southern part, humid; western and northern part, subhumid. Mean annual rainfall ranges from about 50 inches at Camuy along the coast to 78 inches along the southern boundary of this area. Nearly continuous northeast trade winds fan the entire district. The climate is favorable for a nearly ideal continuous growing season. The cultivated areas receiving less than 60 inches of rain are generally irrigated.

Present vegetation.—Nearly every kind of crop grown on the island can be found on the smooth areas, and mesophytic forests abound in the numerous steep jagged limestone hills and cliffs.

Parent material.—Tertiary limestone residuum. In some of the valleys the limestone has weathered to such an extent that the soil materials are 30 or 40 feet deep.

Soils.—Soils of the Coto series have yellowish-brown, slightly acid, permeable, friable, softly granular surface soils about 8 inches thick, underlain by reddish-yellow slightly heavier textured, permeable, slightly acid material that rests on limestone rocks at depths ranging from 2 to 10 feet. Most of the material from the surface to the underlying rock has a very high content of clay, but the particles

FIGURE 49.—This vertical aerial view shows an average, densely populated 600-acre tract of the Coto-Bayamón area that has nearly 150 rural dwellings and about 700 inhabitants. The letter symbols on the enclosed areas indicate types of soil and land use as follows: Ac, Almirante clay, heavy, yellowish-colored, poor for most crops; An, Almirante sandy clay, heavy, yellowish-colored, poor for most crops; Bc, Bayamón clay, deep red, heavy textured, fair for all crops; Bs, Bayamón sandy clay, deep red, heavy textured, fair for all crops, very similar to Bayamón clay; By, Bayamón sandy clay loam, deep red, fairly heavy textured, fair for sugarcane and pineapples; Bf, Bayamón fine sandy loam, deep sandy soil, good for citrus and truck crops; Cz, Corozo fine sand, white and porous, very poor for all crops; Ey, Espinosa sandy clay, yellowish-red, fairly heavy, only fair for most crops; Ea, Espinosa loamy sand, yellowish-red sandy soil, good for citrus and truck crops; Sx, Santa Clara clay, black, heavy, plastic medium-deep soil, good for sugarcane; Sk, Soller clay, hilly phase, black, heavy, plastic shallow soil, excellent for grass; Su, St. Lucie fine sand, deep, white, and porous, very poor for all crops; Ta, Tanamá stony clay, shallow soil used only for brush; Vf, Vega Alta fine sandy loam, reddish-brown sandy soil, excellent for citrus; Vi, Vega Alta loamy fine sand, reddish-brown sandy soil, excellent for citrus.

are so grouped together that the soil has the physical characteristics commonly associated with a loam or sandy loam rather than a clay. Water and plant roots penetrate readily. The Bayamón soils differ from the Coto soils in that they are reddish brown in the surface, red in the subsoil, acid in reaction, deeper, and occur in areas of higher rainfall. These soils occur in the valleys and they are closely associated with many other soil series, especially the Tanamá soils which occur on the brush-covered, steep hills and have very shallow, acid, red soils. In many places the Tanamá soils are not more than 3 inches thick and there is much bare rock outcrop.

Use.—Owing to their great depth and permeability the soils of the valleys are adapted to nearly every crop grown on the island. Yields are low, however, because the soils are so permeable that leaching has caused a deficiency of bases and plant nutrients. These soils, therefore, need considerable fertilizer, especially phosphorous and nitrogen. The soils on the hills are so shallow that they can be used only for forest and sweetpotatoes.

Rosario-Nipe Areas

[Laterite soils]

Geographic setting.—The Rosario-Nipe soil areas are long narrow belts in the west-central part of the uplands of Puerto Rico. These areas are characterized by infertile red-staining soils, scanty vegetation, scarcity of dwellings, and round-topped hills with exceedingly steep, slip-scarred slopes. The elevation ranges from 40 feet near Guanajibo Point along the coast to about 2,000 feet at Santa Ana peak 15 miles inland.

Climate.—Humid (wet-dry), and tropical. Mean annual rainfall ranges from 80 inches at the coast to 100 inches on the highest elevations. Three-fourths of the precipitation falls from May to October, inclusive. Temperature ranges from 55° F. during the coolest nights in winter to 100° during the hottest summer days. The area has almost continuous cool oceanic breezes, long daylight, and torrential rains of short duration. Climate is favorable for a 12-month growing season.

Present vegetation.—Mahogany, mamey, treeferns, sierra palms, mangoes, matojo grass, and cerrillo.

Parent material.— Serpentine.

Soils.—The Nipe series are deep, purplish-red, permeable neutral clay soils high in iron and aluminum hydroxides, with abnormal amounts of chromium and nickel oxides, and low in silicon dioxide. The surface soil contains from five to eight times as much organic matter as the subsoil and is therefore slightly darker in color and has a higher water-holding capacity. Otherwise the soil material differs but slightly in chemical and physical characteristics from the surface to the underlying bedrock, which occurs at a depth of as much as 20 feet. The soil material feels like an inert mineral powder rather than a productive soil. The soil, when either wet or dry, stains objects with which it comes in contact a purplish-red color. Water penetrates rapidly, and the soil does not swell or contract to any noticeable extent at the extremes of moisture content.

The Rosario soils are similar to the Nipe soils except that they occur on steep slopes and are very shallow. The soil material is seldom more than 8 inches thick.

Use.—Rosario soils are used only for forestry, owing to the shallowness of the soil and steepness of the relief. The slow plant growth on both the Nipe and Rosario soils is apparently due to the lack of fertility, the high content of chromium, nickel, and iron, the droughtiness of the soil, or a combination of these factors. Cultivation is limited to a few of the best areas of the Nipe soils that are highly fertilized, although even then numerous irregular-shaped patches will not produce crops. Seeds will germinate and grow for a few weeks, then die. Fertilizer and lime are essential for fair or good yields.

Ponceña-Coamo Areas

[Reddish Chestnut soils (include much Planosol)]

Geographic setting.—The Ponceña-Coamo soil areas include long, narrow, disconnected fertile plains intermediate in position between the arid uplands of southern Puerto Rico and the Santa Isabel-Paso Seco soils along the coast. This

area is characterized by level or undulating fields of productive succulent sugarcane and thick stands of nutritious guinea grass. Only a few houses dot the landscape, but many hundreds of oxen crop the grass or lie in the shade of the widespreading tamarind and algarroba trees. The elevation of this area ranges from 20 to 700 feet above sea level.

Climate.—Tropical and semiarid or subhumid. Mean annual rainfall 45 to 60 inches. Driest months are December to March; wettest months August to November. Temperature averages about 72° F. Most of the days are hot and clear. Nights cool and bright. Continuous plant growth if the land is irrigated or receives sufficient rain.

Present vegetation.—Besides sugarcane and guinea grass, horquetilla, almácigo, tamarind, jagüey, and royal palms are predominant.

Parent materials.—Shaly limestone, tuffaceous rock, and materials washed from hills composed of these rocks.

Soils.—The soils of the Ponceña-Coamo area have nearly black, granular, alkaline, plastic-clay surface soils high in organic matter and bases over subsoils of heavy yellowish-brown silty clay or clay material fairly easily penetrated by plant roots and water. Much soil of these areas is characterized by claypan development and approaches the Planosol in character. Substratum similar to subsoil; extends downward to a depth of 6 or 10 feet; rests on limestone, stratified gravel, or tuffaceous rocks. Some soils of these areas are almost as dark-colored as Chernozem.

Use.—These soils are well adapted to sugarcane and grass, the two principal crops grown. They are fertile, productive, fairly easy to cultivate, and owing to their great depth they have a high water-holding capacity and sufficient area for the distribution of plant roots. These soils need some irrigation and some complete fertilizer for best sugarcane production. Grass grows luxuriantly without either fertilizer or irrigation. The steep areas erode rather severely when improperly planted to clean-cultivated crops.

Santa Isabel-Paso Seco Areas

[Reddish Chestnut (includes much Planosol)]

Geographic setting.—The Santa Isabel-Paso Seco soil areas include small, very gentle sloping alluvial fans along the southern coast of Puerto Rico that are exclusively occupied by sugarcane in the irrigated districts, pasture and corn in the dry-farming areas, and salt-resistant vegetation in areas too salty for sugarcane. The elevation ranges from about 10 to 300 feet above sea level. This area has numerous large haciendas and ranches, but very few small farms.

Climate.—Tropical and semiarid. Mean annual rainfall ranges from 35 to 40 inches, most of which falls during the summer and fall months. Very similar to the climate of the Ponceña-Coamo areas except that there is less rainfall.

Present vegetation.—Xerophytic plants, sugarcane, corn, and guinea grass.

Parent material.—Material washed from neutral and alkaline soils of the uplands.

Soils.—Members of the Santa Isabel series have dark-brown, granular, calcareous, fairly mellow surface soils high in organic matter and bases, underlain by brown or yellowish-brown fairly compact subsoils with prismatic structure and substrata of light yellowish-brown material, highly calcareous, fairly friable, and permeable. This material continues to a depth below 5 or 6 feet. The Paso Seco soils have similar profiles but lack the lime accumulation. Some areas have a high water table and are affected with harmful quantities of salts, a limiting factor in sugarcane production if more than 0.2 percent occurs in the upper 12 inches of the soils. Many other soil series are closely associated with and similar to the Santa Isabel and Paso Seco soils.

Use.—The land is nearly level, shows little or no erosion, and rainfall has not been sufficient to leach out the bases and other plant nutrients. The soil materials have been washed from soils high in plant nutrients, consequently the resulting soils are highly productive, and as they are fairly easily cultivated and occur in level areas that can be irrigated and farmed with modern machinery, they are among the most productive soils for sugarcane in Puerto Rico. Irrigated areas of these soils are intensively farmed to sugarcane year after year, and continually throughout the year (fig. 50). Nonirrigated areas are used for pasture. The carrying capacity is about 1½ acres to an ox.

FIGURE 50.—Aerial view of irrigated sugarcane fields along the south coast of Puerto Rico. The cane grows to the edge of the sea. Some of this land produces 100 tons of sugarcane, or about 14 tons of sugar, to the acre. Note the modern sugar central in the lower left-hand corner and the old hacienda in the upper right-hand corner. (Photograph by U. S. Navy.)

Soller-Aguilita Areas

[Rendzina (humid and semiarid)]

Geographic setting.—The Soller-Aguilita soil areas include long and fairly wide belts of the undulating or hilly coastal plains along the northern and southern

coasts of Puerto Rico, the center of St. Croix, the eastern tip of Vieques, and all of Mona Island. These areas are characterized by their dark-colored soils underlain by limestone, lack of streams, numerous houses, and small farms. The drier districts have larger farms and fewer houses than the humid areas. The elevation ranges from 20 to 1,500 feet.

Climate.—Humid in the northern part of Puerto Rico; all other areas are semiarid. Mean annual rainfall ranges from 35 inches on Mona Island to 110 inches near San Sebastian.

Present vegetation.—Xerophytic plants in semiarid districts and mesophytic plants in humid districts. Cultivated plants include guinea grass, corn, and tobacco in arid districts and sugarcane, beans, pigeon peas, yuca (cassava), sweetpotatoes, yautia, bananas, coffee, tobacco, and corn in humid districts.

Parent materials.—Soft Tertiary limestone in all areas and some marl in St. Croix.

Soils.—The soils of this area, of which the Soller series in the humid districts and Aguilita series in the semiarid districts are good examples, have nearly black, heavy, calcareous granular clay surface soils very high in organic matter. The subsoil occurs at a depth ranging from 3 inches on the steep slopes to 20 inches on the lower gentle slopes. It is yellowish-brown, silty, plastic calcareous material that is underlain at a shallow depth by soft white limestone or marl. The surface soil is nearly black in the humid districts and less dark colored in arid districts.

Use.—The use of the soils depends principally upon the mean annual rainfall and the relief. The steeper the relief the shallower are the soils and the higher the ratio of grass to cultivated crops. The higher the rainfall the deeper the soil and the higher the ratio of cultivated crops to grass and trees. The carrying capacity during the year in the arid districts is about 6 acres to an animal (horse or ox) and in the humid districts about 2 acres. The grass produced in both the arid and humid districts is of a highly nutritious quality. The yields of cultivated crops are low compared to those on the alluvial soils, but the quality is good.

Erosion control is one of the most serious problems on these shallow soils that are continually being planted to clean-cultivated crops without regard to slope or direction of the rows.

Descalabrado-Guayama Areas

[Lithosols and shallow soils (arid-subhumid)]

Geographic setting.—The Descalabrado-Guayama soil areas include the larger part of the cattle range of southern Puerto Rico, the islands of Culebra, St. Thomas, St. Johns, and most of the islands of Vieques and St. Croix. These areas are characterized by steep high hills, intermittent streams, shallow brown soils, and hundreds of livestock grazing in the nutritious guinea grass pastures. These areas are among the most thinly populated parts of the islands. The elevations range from 20 to 2,000 feet.

Climate.—Arid to subhumid. Mean annual rainfall ranges from 25 to 65 inches, most of which falls during the summer and fall months. Days long, clear, and hot; nights cool and bright. Southern slopes receive less rainfall, have higher evaporation, more dehydration, and less dense vegetation than northern slopes.

Present vegetation.—Guinea grass and xerophytic trees, such as algarroba, almácigo, tamarind, ceiba, and ucar.

Parent materials.—Tuffaceous rocks and shale.

Soils.—The Descalabrado soils have brown or dark-brown granular neutral or alkaline clay or silty clay loam surface soils underlain by shallow light-brown clay or silty clay neutral or calcareous subsoils that contain considerable partially disintegrated rock and generally grade into tuffaceous bedrock at a depth ranging from 8 to 18 inches. The Guayama soils differ from the Descalabrado soils in that they are reddish brown throughout and are derived from a greenish-gray calcareous shale.

Use.—The soils in this area are used for pasture and forestry. Grass grows rapidly during the rainy season and cures nicely during the dry season. The quality of grass is excellent, but the quantity is not so abundant as on the level areas of the closely associated Ponceña, Coamo, Santa Isabel, and Paso Seco soils, and in areas of more rainfall. The carrying capacity ranges from 2 to 4 acres to an ox during the year. Areas that have not been cleared for the planting of grass, such as most of the St. Johns and St. Thomas Islands and other areas, support

trees and bushes. The trees grow slowly owing to the small amount of moisture. The land is so steep that only a portion of the limited rainfall enters the soils.

Múcara-Naranjito Areas

[Lithosols and shallow soils (humid)]

Geographic setting.—The Múcara-Naranjito soil areas cover some of the most densely populated parts of rural Puerto Rico, including the large tobacco and subsistence-crop belt in the east-central part of the island. They are characterized by steep A-shaped cultivated hills and V-shaped rock-bottomed ravines. The relief gradually becomes less rough toward the coastal plains and inner valleys. The elevation ranges from 30 to 2,000 feet.

Climate.—Humid and subhumid. Mean annual rainfall ranges from 65 to 100 inches, most of which falls during the summer and fall months. Days hot and long; nights cool and bright. Entire area fanned by cool ocean breezes during the day and land breezes at night. Owing to the warm, moist tropical climate, rocks weather rapidly and soils develop much faster than in temperate zones. Decomposition of the rocks nearly keeps pace with erosion on many of the fairly steep slopes.

Present vegetation.—Mesophytic plants of many kinds in addition to all crops commonly grown on the island.

Parent materials.—Tuffaceous rocks and igneous intrusives.

Soils.—These well-drained soils range from grayish brown to black and have a fairly granular, neutral or slightly acid silty clay or clay surface soil about 6 inches thick, which is underlain by brown neutral or slightly acid heavy silty clay and by disintegrated tuffaceous rocks at a depth ranging from 8 to 18 inches, depending upon the slope—the steeper the slope the shallower the soil.

Use.—Owing to the steep relief and thinness of the soil, shallow-rooted crops are naturally better adapted to these soils than sugarcane or citrus fruits. Nearly all of the island's best quality tobacco, and probably 60 percent of all the subsistence crops, are produced on the soils in this area. In many countries similar land would be considered too rough and stony for agriculture, but the population pressure is so great in Puerto Rico that thousands of people are forced into the steep hills in order to raise subsistence crops to supplement the wages received from sugar centrals, tobacco-ribbing shops, and other industries. These soils, although shallow and eroded are better adapted to the type of garden farming practiced by the jibaro (small subsistence) farmers than the deep permeable red soils, which have been leached of their bases and have had no chance to be rejuvenated. The jibaro farmers fertilize tobacco but seldom any of the subsistence crops; the Múcara and associated soils are shallow and young and have a considerable supply of plant nutrients, and the rapid disintegration of the parent material liberates available bases. Red acid soils, such as members of the Catalina and Los Guineos series, must be fertilized, and the jibaro gardener is not in a position to go to that expense.

Alluvial Soil Areas

Toa, Coloso, and San Anton

Geographic setting.—The soils of the alluvial land of which the Toa, Coloso, and San Anton series are good representatives, are the most productive soils in Puerto Rico. They occur as a nearly continuous band around the island within 4 miles of the coast. These valuable soils are characterized by level checkerboard fields almost exclusively of sugarcane. Most of the land is owned or operated by large sugar centrals. The land is so valuable that few houses are built except along the main highways and at the sugar centrals, haciendas, and colonias (small farms operated by owners who grow sugarcane under contract for sugar companies). Elevation ranges from sea level to about 20 feet above.

Climate.—Mean annual rainfall ranges from 30 inches along the southern coast to 80 inches along the western coast. Nearly all areas receiving less than 60 inches of rain are irrigated. From 10 to 12 acre-feet of water, in 20 or 25 irrigations, is used on a gran cultura, or 18-month sugarcane crop, in districts receiving 30 to 40 inches of rainfall.

Present vegetation.—Nearly 85 percent of the area is occupied by sugarcane, about 10 percent is in malojilla grass, and 5 percent is covered by swamp vegetation such as mangroves.

Parent material.—These soils have been formed from water-transported erosional material, which is continually being washed from the hills of the interior.

Soils.—The soils in this area have a brown or dark grayish-brown, granular, mellow, fertile surface material ranging from sands to clays in texture and from alkaline to acid in reaction. The higher the rainfall the more acid the soils as a general rule. Subsoils are slightly heavier and more alkaline than surface soils and are generally deep except in gravelly areas. Some soils have mottled subsoils, which show lack of good drainage. Substrata are sandy and gravelly.

The Toa and Coloso soils occur in humid districts and the San Anton soils in semiarid districts. The Coloso soils are similar to the Toa soils except that they are poorly drained. Many other soil series are closely associated with these soils on the alluvial plains. Among these are the Viví soils, formed largely of granitic materials, strongly acid, and generally sandy.

Use.—These soils are excellent for agricultural crops because they are easily worked, deep, fairly high in bases and organic matter, and generally free from harmful salts and gravel. Most areas receiving less than 70 inches of annual rainfall are irrigated. Although these soils are suitable for many crops, very few can compete with sugarcane for profit on these high-priced lands.

Some of the alluvial soils have been in nearly continuous cultivation to sugarcane for about 80 years and are now producing higher yields than ever before, owing to efficient management, excellent sugarcane varieties, insect and disease control, and sufficient fertilizer. The prosperity of Puerto Rico depends to a great extent upon the use of these soils, which in turn depends on the price of sugar and the extent to which production is curtailed.

Bog Soil Areas

Geographic setting.—The Bog soils of the coastal lowlands occupy low, flat areas adjacent to or only a few miles from the coast. Under natural conditions the soils are wet—in many places they are covered with water to depths varying from a few inches to a few feet.

Climate.—Chiefly humid to subhumid, partly semiarid.

Native vegetation.—Mangroves or similar trees, reeds, sedges, cattails, ferns, and grasses.

Parent materials.—Organic residue from plants with some alluvial sediments. Some salt from tidal waters.

Soils.—The Bog soils—peat and muck—vary considerably owing to the variation in plant associations, water level, and salt-water content. They are usually characterized by a dark, organic surface layer from a few inches to 1 or 2 feet thick, over fibrous peat, with bluish clay or sand at from 1 to 6 or more feet in depth.

Use.—Drainage is difficult and expensive in most areas. When the soils are drained, sugarcane (fertilized) and malojilla grass produce fair yields provided they are not disastrously inundated during part of the growing season. Charcoal making is the chief enterprise on the greater part of the areas covered by trees.

SOILS OF THE PANAMA CANAL ZONE

Frijoles-Gatun Area

Geographic setting.—The land area of the Panama Canal Zone is characterized by hilly relief, the only flat lands being the areas of savanna near the Pacific Ocean. The land physically suited to agriculture is probably not more than 20 percent of the total area.

Climate.—The climate is humid and tropical and characterized by definite wet and dry seasons. The average annual rainfall ranges across the Isthmus from 67.67 inches at Balboa on the Pacific side to 127.25 inches at Colon on the Atlantic side. The mean annual temperature is about 80° F. with little variation during the year.

Native vegetation.—Forests of tropical hardwood trees and many palms.

Parent materials.—Sedimentary rocks, including limestone, claystone, and sand-

stone with little or no quartz, and igneous rocks, including basalt, andesite, diorite, and rhyolite.

Soils.—The agriculture is dominated by three red clays that are very similar in their properties. Frijoles clay is a deep-red clay slightly brownish at the surface, underlain by a brick-red clay. This soil has developed from dark-colored basic igneous rocks. The Gatun clay has a profile similar to that of Frijoles clay, but it has developed from sedminetary rocks. Arraiján clay is also a red clay developed over igneous rocks including diorite, andesite, and basalt. These soils are extremely friable as compared with the clay soils of humid-temperate regions even when in a moist condition.

Use.—The principal crops of the region are bananas, guinea grass for pasture, rice, vegetables, papayas, mangoes, and other tropical fruits.

SOILS OF ALASKA

Surveys have not been made in sufficient detail to determine the character and extent of the various soils of Alaska. It is known that much of the country is rough and mountainous, and that comparatively little of it is suitable for agricultural development. Two areas are believed to contain the greater part of the potential farming land. One of these is the area surrounding Cook Inlet, including the Kenai Peninsula and extending northward along the Susitna River Valley. The soils are loams and sandy loams interspersed with marshy tracts. The other area is in the Yukon and the Tanana Valleys. The soils are mainly loams and silt loams of fairly high productivity. The soils of both areas offer possibilities for agricultural development. Numerous small patches of tillable land may be found on the islands and shore lines of the southern part of Alaska. Forests, mainly of hemlock, spruce, and birch, cover all areas of possible farming land and also extend up mountain slopes and over poorly drained areas.

Vast stretches of treeless tundra and grassland along the western and northern parts of Alaska are used to some extent for grazing reindeer. There are possibilities of establishing an important enterprise in raising reindeer on the tundra and cattle on the grassland. Parts of the rough, stony, mountainous areas also have potential value as grazing lands and for timber production.

Knik-Muskeg Areas

Geographic setting.—An area of comparatively smooth land, part of which is suitable for farming, extends along the eastern and northern sides of Cook Inlet. It includes the benches and flats along the western side of Kenai Peninsula and the alluvial lands (fig. 51) that border the Matanuska and Susitna Rivers. The area is a lowland, hemmed in on one side by Cook Inlet and on the other by mountains. If this lowland could be seen as a whole, it would appear as a flat plain with a succession of forests, marshes, and lakes, flanked on the land side by rather steep mountains. It is estimated that the area comprises approximately 6,000 square miles, less than one-third of which is tillable and suited to farming. The land that can be used for agriculture is confined to the better-drained low terraces, as frosts prevent the cultivation of the higher terraces and slopes.

Climate.—The mean annual temperature at Anchorage on Kenai Peninsula is 34.4° F., with absolute maximum of 92° and absolute minimum of −36°. Summers are short and the winters long and cold. The average length of frost-free season is 111 days. The average annual precipitation is 14.5 inches, the greater part of which falls in the 5 months from July to October, inclusive.

Native vegetation.—Forests of black and white spruce, aspen, birch, and hemlock exist. In open spaces redtop and other grasses and weeds make a dense growth. The most common vegetation of the muskeg is sphagnum moss and various shrubs and flowering plants.

Parent materials.—Both benchlands and stream bottoms have been built up of materials laid down by water or glacial action, or both. This debris was derived from the adjacent mountains and consists of various igneous rocks. Volcanic ash is also present in the soils over a large part of the region.

Soils (32).—The members of the Knik series are the most extensive soils of the Cook Inlet section and the most favorable for farming. Knik loam, which is representative of the series, has a gray silty loam surface layer about 4 inches thick. The next lower layer is a brown or coffee-brown mellow loam, which grades to a yellowish brown. At any depth from 12 to 26 inches, there is a

yellowish-brown fine sandy loam, containing both large and small gravel. The gravel becomes larger in the lower part. A surface covering of dark brown or black vegetable mold is usually present.

"Muskeg" is the name given to a type of marsh which occurs in large areas in the Cook Inlet section and in numerous small areas scattered through the Knik soils. The material consists of brown or coffee-brown fibrous peat, more or less decomposed. Sphagnum moss makes up a large part of the peat moss. The peat is saturated with water at all times.

Use.—The Knik soils are good farming soils, well suited to the production of grain, potatoes, a large number of vegetables, and hay grasses (fig. 52). Muskeg is not only valueless in itself for farming but it constitutes a detriment to the development of the country, as the numerous strips of this swamp impede transportation and make areas of good land inaccessible. Owing to the acid condition of the Knik soils, applications of lime are generally needed.

FIGURE 51.—Redtop pasture on some of the alluvial lands in the Knik-Muskeg soil area, Alaska.

Fairbanks-Tanana-Gilmore Area

Geographic setting.—A considerable area of comparatively smooth land lies in the interior of Alaska east of the junction of the Yukon and Tanana Rivers. This area includes the bottoms of the lower Tanana and the highlands to the north and the bottoms of the Yukon River. It is estimated that the available farming land covers at least 4,500,000 acres and includes the most productive soils in Alaska. The bottom lands along the rivers are in general smooth and suited to farming. The uplands present a succession of hills, ridges, and mountains, with occasional areas smooth enough for cultivation.

Climate.—The climate of this area is characterized by short, moderately warm summers and long, cold winters. Summer temperatures often reach 90° to 96° F., and in winter temperatures drop to −60° or −70°. The average annual precipitation is light, ranging from 10 to 12 inches, but as it falls in the growing season and evaporation is low, crops rarely suffer.

Native vegetation.—This area is covered by forests of spruce, aspen, birch, and cottonwood, with willow and alder in thickets or as an undergrowth. In addition, a great number of shrubs, grasses, and mosses persist in the forest and grow luxuriantly on the open marshes.

Soils.—The soils of this area have not been studied in detail, but preliminary surveys show (*32*) that they fall into three principal groups: The Tanana soils of the river bottoms, the Fairbanks soils on the well-drained slopes, and the Gilmore soils on the rolling upland. The Tanana soils are mainly sandy. The surface is usually covered by vegetable mold, peat, or muck. The inorganic part of the soil consists of silt, sand, and gravel, and contains a great variety of minerals. The surface soils are in general grayish brown, frequently mottled with gray or rusty brown.

The Fairbanks soils occur on well-drained slopes (fig. 53) and cover an area of

FIGURE 52.—Subsistence crops growing on the warm well-drained southern slopes near Matanuska Junction, Alaska.

FIGURE 53.—Typical view of Fairbanks silt loam near Fairbanks, Alaska. Cleared areas of these well-drained soils produce good yields of potatoes, small grains, and vegetables.

approximately 500,000 acres. The Fairbanks silt loam is a deep, mellow, brown silt loam underlain by a yellowish-brown, moderately compact silt loam. This soil appears to be derived from wind-laid material.

The greater part of the upland is covered by soils derived from micaceous schists and other metamorphic rocks. The Gilmore loam and silt loam are the most extensive of these soils. The surface soils are brown loams or silt loams with a considerable quantity of micaceous particles. The subsoils are yellowish-brown or grayish-brown micaceous, gritty loams. A number of soils of minor importance occupy areas scattered over this region, and poorly drained areas of peat and muskeg occur on the flat portions. In the Yukon Valley an extensive area of alluvial soils includes many soils, of which the most promising types for farming are those of the Yukon series. These are brown soils resembling the Tanana soils but differing from them in being less acid.

Use.—The better-drained types of the Tanana series produce good crops of vegetables and hay. The Fairbanks soils produce large crops of potatoes and small grains, including wheat, and vegetables of many kinds are grown with success. The deeper areas of Gilmore soils are suited to about the same crops as the Fairbanks soils, but average yields over these areas will be lower. It has been demonstrated that the Yukon-Tanana area has possibilities for general farming, stock raising, and dairying. There is no doubt as to the possibility of obtaining the necessary feed for stock from the native grasses and from the forage and root crops that can be grown.

Tundra and Grassland

Geographic setting.—A vast treeless area stretches around the western and northern parts of Alaska. On the basis of vegetative cover, the area may be divided into grassland and tundra. The grassland covers the Alaska Peninsula, the Aleutian Islands, and the south slopes of the Alaska Range; tundra occupies a large section bordering Bering Sea and the Arctic Ocean.

Almost nothing is known of the soil material underlying the grasslands and tundra. In the case of the tundra, the mineral part of the soil apparently does not greatly affect the landscape. Tundra is a product of climatic conditions. Grasses, sedges, mosses, and lichens have formed a mat of organic material, living and dead, over the surface.

Three general types of tundra are recognized—wet tundra, dry tundra, and rocky or ridge tundra. Wet tundra is most extensive, covering the flat and gently rolling plains near Bering Sea and the Arctic Ocean, and is interspersed with dry tundra on better-drained slopes. Dry tundra covers strongly rolling areas in regions of very low temperature.

Climate.—The Aleutian Islands and the Alaska Peninsula have a comparatively mild climate. The precipitation is from 60 to 80 inches and the mean annual temperature about 40° F. The tundra area is much colder. Along the Bering Sea the mean summer temperature varies from 44° to 54°, and the mean annual temperature is from 25° to 33°. The precipitation at Nome is about 17 inches. At Nome, and at Barrow on the Arctic Ocean, frost may occur in any month in the year.

Native vegetation.—The grassland supports a dense cover of grasses and weeds with a minor admixture of vines and shrubs (*393*). The average composition of the tundra cover is about 30 percent lichens, 25 percent sedges, 25 percent shrubs, and 20 percent grasses, weeds, and mosses. The dry tundra has a larger proportion of large shrubs, grasses, and weeds, while the ridge tundra has more of the lichens.

Use.—The grassland areas furnish excellent summer grazing for livestock, but at present little use is being made of the grass resources. The introduction of reindeer into Alaska within recent years has led to the utilization of large areas of the tundra. The lichens, which form a large part of the food of the reindeer, grow abundantly over the tundra. It has been estimated that 4,000,000 reindeer can be supported on this food supply.

SOILS OF THE HAWAIIAN ISLANDS

The Hawaiian Archipelago is a chain of islands nearly 1,600 miles long near the center of the North Pacific Ocean. The larger islands form a group about 375 miles long at the east end of the chain and entirely within the Tropics.

The large, high, inhabited islands considered in this article are Hawaii, 4,016 square miles; Maui, 728; Molokai, 261; Lanai, 139; Kahoolawe, 44; Oahu, 598; Kauai, 547; and Niihau, 73 square miles. The total area of the remaining small islands is only about 6 square miles.

The islands are great volcanic mountains rising from ocean depths of 15,000 to 18,000 feet to a maximum elevation (Mauna Kea) of 13,825 feet above sea level. The islands at the west end of the group are apparently older than those farther east where there is still extensive active volcanism. These western islands have more deeply and thoroughly weathered mantles of soil material and are more maturely dissected—titanic erosion has produced canyons 3,000 feet deep on the island of Kauai. The island of Hawaii, comprising two-thirds of the area of the archipelago, consists of five volcanic mountains, some of them active, connected by saddles formed by coalescing or overlapping lava flows. There is little dissection and there are no streams except in heavy rains.

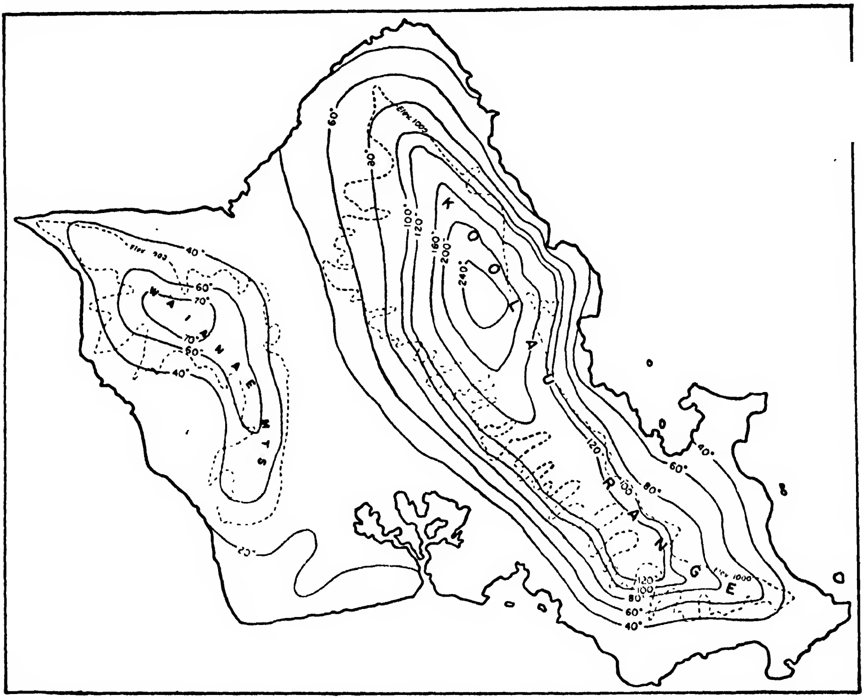


FIGURE 54.—Map of Oahu, showing the effect of topography and elevation on distribution of rainfall.

The northeast trade winds, blowing in from cool ocean currents, modify the temperatures and carry a heavy load of moisture, much of which is dropped on the islands. Rough relief and great range in elevation produce great differences in temperature and rainfall within short distances. Temperatures are generally lower than in similar latitudes and altitudes elsewhere. There is a decrease of about 1° F. for each rise in elevation of 300 feet. At Honolulu, 50 feet above sea level, the mean annual temperature is 74.4°; at Humuula on Hawaii, at an elevation of 6,685 feet, it is 52°. Freezing temperatures, frost, and snow very rarely occur below 4,000 feet but are common in winter above 6,000 feet.

Rainfall varies extremely from place to place—the range being from less than 20 inches to almost 500 inches annually. It is heaviest on windward slopes from 300 to 5,000 feet above the sea. The lowlands receive less moisture, and the lower leeward slopes and plains are arid or semiarid. The higher mountains have relatively low rainfall on the upper reaches, the moisture-laden winds having lost most of their rain below 6,000 feet. There are no extreme wet and dry

seasons as in much of the Tropics, but there is usually more rainfall in summer than in winter. The distribution of rainfall on Oahu is shown on the sketch map (fig. 54), which illustrates the effect of topography and elevation on rainfall in the trade-wind belt (fig. 55), though the high mountain masses on Hawaii and Maui have some modifying effect.[4]

The isolation of the islands and their great diversity of soil, relief, drainage, and climate has led to the development of a unique flora and one that is extremely diversified. Many of the native species are found nowhere else. There are more than 1,000 native flowering plants, including 300 kinds of trees, about 150 species of ferns, among them treeferns 25 to 30 feet high, and hundreds of species of mosses, fungi, and algae.

Many hundreds of plant species have been introduced. These include most of the important tropical ornamentals and food plants, particularly sugarcane and pineapples, now dominant commercial crops of the islands.

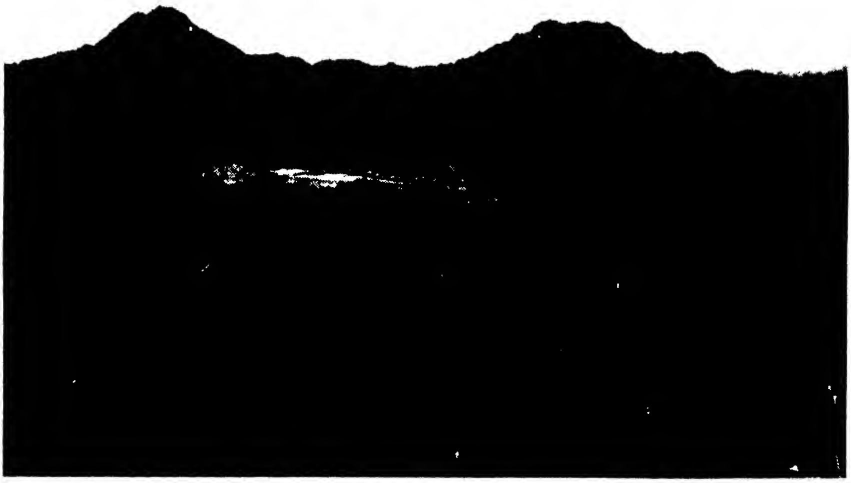


FIGURE 55.—Nuuanu Pali on the windward side of Oahu. This type of dissection is characteristic of the older mountain ranges under high rainfall. (Photograph by U. S. Army.)

The parent rocks of the soils of the Hawaiian Islands consist of volcanic materials, coral limestone, unconsolidated marine and alluvial sands and finer sediments, and in the southern part of the island of Hawaii, of loess. The volcanic materials which cover more than 90 percent of the area of the islands consist of lava, cinders, and volcanic ash. The lava is of various textures, chief among which are the rough, scoriaceous form locally known as aa, and the denser, harder, smoother type known as pahoehoe. The lava is for the most part of the basalt or basaltic type, although andesites are recognized. They are high in calcium, iron, magnesium, and titanium as compared to the other igneous rocks of the world.

The chief differences in the properties of the soils of the Hawaiian Islands are due to differences in the geological age of the parent rocks, which ranges from a few months to many thousands of years; to differences in the texture or physical composition of the rocks, which ranges from loose volcanic ash and loess to hard dense lava; to differences in the climate, which varies from arid to very humid, and from uniformly warm and frost-free at sea level to definitely cold on the higher mountains; to variations in physiographic features, which range from rug-

[4] Climatological data from records of the U. S. Weather Bureau, Hawaii section.

ged mountains to undulating plateaus and low coastal flats; to differences in drainage conditions; and, finally, to differences in vegetation, which result from the interaction of all the foregoing factors.

Owing in part to the geological youth of the parent materials and in part to the rugged topography of the islands, less than 10 percent of the area has deep or well-developed soils. A generalized classification of the lands of the islands therefore is based partly on physiographic and geographic features, rather than entirely on soil features. The limited scale of the soil map (at the end of the Yearbook) has required generalization and the number of units was limited arbitrarily to 12. These units, which are essentially geographical, are briefly described.

Yellowish-Brown and Reddish-Brown Lateritic Soils

Geographic setting.—The larger areas of soils of this group are shown on the soil map on Hawaii, Maui, Oahu, and Kauai—islands large enough to catch and precipitate the moisture of the trade winds. On Hawaii the largest body occurs on the northeastern or windward slope, from the coast to elevations of about 1,700 feet. The average slope is about 12 feet to the mile; the surface is undulating to rolling and cut by numerous deep steep-sided gullies. The other areas on Hawaii, Maui, Oahu, and Kauai are of somewhat similar relief.

Climate.—Tropical and largely humid, though the rainfall differs widely in different areas. The southern part of the large area on Hawaii has a range in rainfall from 135 to 275 inches. It is well distributed throughout the year, though heavy downpours of 12 inches to as much as 30 inches in 24 hours may occur. In other areas the rainfall is lower and there are occasional periods of drought. The area on Oahu is distinctly drier, with an annual rainfall of between 30 and 40 inches. Irrigation is used in sugarcane production both in Oahu and in the drier areas of the other islands.

Native vegetation.—The original vegetation, which consisted mainly of heavy rain forest, is now largely removed.

Parent materials.—Weathered volcanic rocks.

Soils.—This group of soils is actually a combination of two closely related groups. The soils are generally deep friable clays and clay loams of a kind characteristic of the humid Tropics and sub-Tropics. Colors range from yellowish brown to reddish brown, the degree of redness apparently being associated with soil humidity, the drier soils being redder. The distinctions between surface soils and subsoils are not sharp as in the well-developed soils of temperate regions. Texture and structure are remarkably uniform throughout. Surface soils generally are definitely darker in color than the subsoils owing to a higher percentage of organic matter, though organic matter extends deeply into the subsoil. Physically these soils are featured by their permeability to moisture and air, their granular structure, friability, high percentage of colloids, and high moisture equivalents. Chemically, they have a high content of organic matter, hydrous oxides of iron and aluminum, manganese and titanium; they are low in silica, calcium, potassium, and sodium; and they have, in general, a marked degree of phosphorus fixation, although this feature, as well as other features, is variable within the group. The soil reaction is distinctly acid in most areas, though on Oahu, where rainfall is comparatively low, the soils are only slightly acid or neutral. In the extreme north end of Hawaii the soils are apparently older and have heavier, somewhat denser subsoils than in most other places. On Oahu and Maui bedrock occurs at comparatively shallow depths and rough and steeply sloping lands are in places stony. The soils on Oahu have a purplish hue, probably due to a high content of manganese.

Use.—The more important crops are sugarcane (grown under irrigation in many places) and pineapples—the principal crop on Oahu and Maui. Some of the land is used for pasture, especially on Maui. Cropland is heavily fertilized.

Yellowish-Brown and Reddish-Brown Lateritic Soils (Forested)

Geographic setting.—The areas indicated as forested differ from the other areas of Yellowish-Brown and Reddish-Brown Lateritic soils in their forest cover. These lands remain in forest chiefly because of their high elevation—generally above the limit of sugarcane production—and their relatively unfavorable location and relief. Some of the soil is definitely shallower than the cultivated Yellowish-Brown and Reddish-Brown Lateritic soils. All the areas indicated

on the soil map are on Hawaii. They occur at elevations ranging from 1,500 to 5,000 feet on the windward slopes of Mauna Kea and Mauna Loa and on the crest of Kohala Mountain. The lands are only gently sloping or nearly level above Olaa. There is some degree of dissection by streams or gulches.

Climate.—The rainfall varies from about 100 inches to more than 250 inches. The temperatures are generally too low for profitable cane production.

Native vegetation.—Tropical rain forest with many treeferns.

Soils.—The soils are variable in color, ranging from dark reddish brown to dark yellowish brown, and are definitely high in organic matter in the upper layer. Mottling is an occasional feature of the soil; the texture is dominantly clay; the structure is variable.

Use.—These lands are not suited to cultivated crops. The better grasses do not grow well and the best present use is for forest. Much of the land is important as watershed, and for such use forest cover is best.

FIGURE 56.—Recently planted pineapple field with paper ground cover in lower central portion. Characteristic topography near borders of central plateau. (Photograph by U. S. Army.)

Reddish Brown and Red Desert Soils

Geographic setting.—This group of soils includes the deeper soils of the drier parts of the islands. Areas are mapped on all the islands except Oahu. The land lies mostly at the lower elevations—ranging from sea level to about 1,750 feet—and the surface consists largely of gently sloping plains, though some areas are steeply sloping or rolling and land unprotected by vegetation is severely gullied.

Climate.—Tropical and arid or semiarid. The average annual rainfall ranges from 10 to 40 inches in different localities.

Native vegetation.—The predominant vegetation on these soils on Hawaii consists of manienie grass, with some ilima and lantana; on Maui, algeroba, cacti, and pili grass; Molokai has a covering of mixed grasses, algeroba, and ilima; on Lanai and Kauai the land is largely cultivated. The native vegetation on Kauai, where present, is somewhat similar to that on Maui.

FIGURE 57. These photographs illustrate the progress of soil formation in the humid Tropics. *A*, Recent lava flows with a few plants growing out of deep cracks. *B*, Lava flow about 55 years old, now covered with vegetation. The soil is limited to a thin film less than one-half inch in thickness. *C*, Characteristic jungle of tropical vegetation with 1 or 2 inches of soil over the rocks. *D*, Profile of a young soil only 24 inches thick but able to support a luxuriant vegetation of native or cultivated plants. The soil is permeated with tiny roots, which together with its low silica-sesquioxide ratio and permeability to water make erosion almost impossible.

Parent materials.—These soils are developed from a great variety of materials. On Hawaii they are mainly wind-laid deposits or loess, varying from sands to very fine sands and silts; on Maui, mixed alluvial and marine materials including coral sands; on Molokai, chiefly lava; and on Lanai, volcanic materials, partly ash.

Soils.—Common features of these soils are their generally reddish-brown and brown colors, alkaline or neutral reaction throughout, and their development under a comparatively dry climate. They range in texture from sand to clay. The soils of the area on the southern end of Hawaii are distinctly less red than those on the other islands; they have brown or dark-brown silty or sandy surface soils over loose silty subsoils with some accumulation of lime in the deeper part. On Molokai the soils are red-brown or brown friable crumb-structured clay loam or silty clay, much the same from the surface down. At elevations above 750 feet there is a grayish-brown surface soil and a fine nutlike structure in the subsoil. Lime carbonate flecks are visible around stones in some places. The manganese content of the soil is high. On Kaui, these soils are red throughout.

Use.—On Hawaii and Maui these soils are used largely for grazing beef cattle and sheep. Grazing is also important on Molokai and Lanai, though gardening and pineapple culture are also practiced (fig. 56). On Kaui the land is used mostly for sugarcane under irrigation.

Erosion is severe on the steeper lands where they are overgrazed or where clean culture is practiced, as with pineapples.

Lithosols and Shallow Soils (Humid)

Geographic setting.—The soils of this group are shallow soils over volcanic rock—mostly recent lava flows—on Hawaii. Other areas are on the east end of Maui and on the east side of Kauai where natural erosion has partially kept pace with weathering. The large area on the east side of Hawaii (fig. 57) consists of nearly level or undulating land with a gradual general slope to the sea. On the west side of the island on the lee slopes of Mauna Loa and Hualalai, extending from sea level to an elevation of more than 5,000 feet, is an area known as the Kona region. On Maui and Kauai the land is largely undulating to rolling or hilly, with a few small, comparatively level areas.

Climate.—Tropical to cool; humid except in the lower part of the Kona region. The range of average annual rainfall in different localities is from 25 to 200 inches. There are frequent snowfalls and frosts during the winter at the higher elevations. A blanket of fog covers the higher parts of the Kona region much of the time.

Native vegetation.—The climate is favorable in many places for luxuriant rain forest, but because of shallow soils much of the land has a cover of small trees and brush with small tracts of grassland. In the Kona region, the vegetation zones as well as the soil belts roughly follow the climatic belts (*306*). Much of the land between 750 and 1,800 feet has been cleared for cultivation. Higher areas are dominated by ohia and treeferns. At 5,000 feet much of the land is in grass, though the original vegetation consisted largely of koa, aaka, aalili, mamani, sandalwood, and ferns. On Kauai the present vegetation is largely of guava and grasses.

Parent materials.—Lavas and volcanic cinders and ash.

Soils.—The soils are predominantly very shallow—in many places consisting largely of a thin layer of dark-brown organic matter mixed with small lava fragments and fine earth over lava bedrock. Rock outcrops are numerous. In the middle elevations in the Kona district, the soil, where deep enough to develop any definite characteristics, consists of grayish-brown friable clay loam or yellowish-brown or reddish-brown friable pervious clay with good tilth and water-holding properties. At higher elevations the soils are darker and there are many areas of organic soils. On Maui the surface soils are generally friable, granular, dark grayish-brown loams or clay loams, over brown or yellowish-brown friable porous subsoils, with substrata of cinders and ash overlying lava. The small areas on Kauai differ from those on the other islands in being much older geologically and having a thicker mantle of weathered materials. The soils are not deep, however, and consist of pale grayish-brown granular silty clay loam with little change in color, consistence, or texture above bedrock. A few more level areas have deeper soils with grayish surface soil and mottled subsoil. The soils are acid throughout.

Use.—The principal use of much of these areas is for pasture. In the eastern part of Hawaii a few areas are cleared and cultivated—partly in sugarcane and partly in vegetables and fruits. In the middle elevations of the Kona district,

coffee, fruits, and vegetables are grown. On Maui some land is cleared and used for sugarcane, but most is used for pasture and forest.

Lithosols and Shallow Soils (Arid and Subhumid)

Geographic setting.—These soils are mostly on the lower leeward (western) slopes of Hawaii and Maui with small areas on Molokai. The area at the northeast tip of Hawaii extends from sea level to about 2,500 feet. The area in the central part of Molokai is moderately to strongly sloping and so dissected with deep gulches that most of it is rough and broken.

Climate.—Tropical and arid or subhumid. The average annual rainfall ranges from less than 10 inches to 75 inches in different places. It is seasonal, falling mostly from November to April, and the variation from year to year is great.

Native vegetation.—Consists largely of small trees, shrubs, and grasses, including ilima, false ilima, pili grass, *Sporobolus*, *Cynodon*, *Paspalum*, guava, lantana, algeroba, and cacti, with manienie grass at the higher elevations where moisture is more abundant.

Parent materials.—Lava and volcanic ash and cinders.

Soils.—The soils are shallow and commonly covered with rock fragments. On Hawaii, sandy loams and loams are dominant. The upper subsoil is very dark brown and has a roughly prismatic structure, and lime carbonate is accumulated on the surface of rocks and in the subsoil. On Maui the surface soil is brown or grayish-brown loam and the subsoil is prismatic brown loam resting on volcanic material. The reaction is alkaline throughout. On Molokai the soils have dark-gray or purplish-gray friable, soft, nut-structured surface soils, over yellowish-brown or brown nut-structured subsoils, commonly slightly lighter-textured than the surface soils and containing much titanium. The subsoil grades into gray, soft, rotten rock. The texture of surface and subsoils ranges from silt loam to silty clay. pH values range from 6.0 to 7.0 in the surface soil and are about 5.5 at 24 inches.

Use.—The land is used mostly for pasture, though pineapples and vegetables are grown on Maui and Molokai and some of the higher lands on Molokai are in forest reserve. Sheet erosion has removed much of the soil from some of the areas used for pineapples and the land has been abandoned as unsuited to cultivation

Lithosols and Shallow Soils (Grasslands)

Geographic setting.—Areas of these soils are mapped on Hawaii and Maui at elevations ranging from 1,500 to 6,000 feet above sea level. They are mostly on plateaus and intermediate slopes or saddles of the great mountains. The lower part of the area in northern Hawaii is generally undulating to rolling, cut in places by shallow gullies; the higher part, much of which occupies a saddle between mountain peaks, is mostly gently sloping or nearly flat. The area in southern Hawaii consists of a series of small plateaus with undulating local relief, separated by a succession of escarpments. On Maui an area lies on the lower slopes of Mount Haleakala. West and north of the mountain the land is moderately to steeply sloping and, especially to the north, it is considerably dissected by small gulches.

Climate.—Warm to cool, and humid to subhumid. Average annual rainfall ranges from 25 to 100 inches. Fog is common above 4,000 feet and occasional frost and light snow occur at 6,000 feet.

Vegetation.—Largely grass. Hilo grass, Bermuda grass, white clover, and vetch are prominent in the pastures. Scattered trees occur, some of them remnants of a former rain forest.

Parent materials.—Lava, volcanic cinders, and ash.

Soils.—Variable in texture and depth, but mostly shallow. At the lower elevations in the northern part of Hawaii the soils are dark grayish-brown loams and friable silty clays over brown or yellowish-brown silty clay subsoils with a crumb or nutlike structure. The deeper subsoils are in places strongly acid, yellow clay, or loose loamy materials from volcanic ash. At the higher elevations, the soils are generally loose loams or sandy loams of brown or yellowish-brown color. Much of the soil material is simply disintegrating rock and the bedrock lies at 1 to 2 feet below the surface. In places a heavier nutlike subsoil is present. In the southern part of Hawaii, the dark loamy soils lie over layers of volcanic sand,

fine gravel, and sandy loams. Small areas have reddish-yellow, very friable subsoils. On Maui, the dark-brown loam and fine sandy loam surface soils overlie yellowish-brown or brown friable subsoils, with disintegrating rock at 2 or 3 feet. In places where the mantle is deeper a layer of grayish-brown clay or clay loam may occur between subsoil and rock.

Use.—The land is used largely for pasture. Small areas of the deeper soils are used or could be used for diversified farming or production of feed crops or vegetables.

Mixed Lateritic and Alluvial Soils

Geographic setting.—These soils occupy a number of small areas of nearly level or gently sloping coastal lowlands on Maui, Kauai, and Oahu.

Climate.—Tropical and semiarid. Rainfall varies from 20 to 40 inches. Much of the land is irrigated. There is much sunshine throughout the year.

Vegetation.—Native vegetation removed. Land cultivated.

Parent materials.—Fine-textured alluvium or marine sediments.

Soils.—The soils are variable, but dominantly dark gray or dark grayish-brown heavy clays underlain by gray or mottled heavy clays generally alkaline in reaction. Some of them have been materially changed by cultivation and fertilization and by recent overwash, in places artificially induced. The latter has produced a soil more friable in structure and somewhat redder in color.

Use.—Sugarcane is the dominant crop and produces very large crops under intensive cultivation, fertilization, and irrigation. Other land produces cultivated feed crops and pasture grasses.

Loose Sands and Coral Rock

On Kauai, Oahu, and Maui are small areas of relatively low coastal plain in which the soils consist of, or are developed from, unconsolidated recent marine and alluvial deposits and residuum from calcareous rock, chiefly coral. These areas are nearly level, with small local ridges and dunes of wind-blown sand. The rainfall ranges from about 20 inches on the lee side of the islands up to 50 inches on the windward side of Kauai. The relatively low rainfall results in a vegetation consisting chiefly of algarroba, ilima, and sandspur, with cacti on the drier sites.

The soils are mostly sandy, the sand consisting of volcanic materials and coral fragments. On the areas underlain by coral rock, there are in places very shallow soils, reddish brown in color where drainage is good, and dark gray or nearly black where drainage is restricted. The heavier marine sediments, which are high in calcium, give rise to dark-colored calcareous soils.

These lands are used chiefly for pasturage, with a very few small tracts under cultivation to sugarcane. There are scattering patches of bananas, watermelons, and other food crops, chiefly on the sandier soils.

Bog Soils

A few areas on the islands are flat enough and wet enough to have favored the accumulation of peat. The largest of these areas is the Alakai Swamp which lies at an elevation of nearly 5,000 feet on Mount Waialea, on Kauai. This mountain top, locally termed a bog or swamp, has a rainfall ranging up to 500 inches a year. The open swamplands are characterized by various grasses, including *Panicum monticola, P. imbricatum, P. isachnoides,* and *Oreobulus furcatus.* The drier areas, upon which there is a moderately dense forest cover, are characterized by ohia lehua (*Metrosideros polymorpha*), kalia (*Elaeocarpus bifidus*), maile (*Alyxia olivaeformis*), and a number of species of *Lobelia* and *Viola.* Associated with the trees and on the borders of the bog are ferns and shrubs of various species, forming a dense cover in the moderately wet situation. The soils are in part peat and muck and in part gray, mineral soils with yellowish clay subsoils. The peat lands are not utilized and the bordering mineral soils are used for forest only.

Rough Broken Land

Rough broken land consists of various types of high or dissected country which is not utilized for cultivated crops. Part of the land is bare or nearly bare of vegetation; part of it is grassland; and part of it is forested. The bare lands are

for the most part very steep cliffs and canyon walls which consist in places of hard bare rock, elsewhere of loose material in which erosion is so rapid as to preclude the growth of vegetation. The various types of rough, broken land are described briefly as follows:

On Kauai, rough broken land comprises about 80 percent of the total area of the island. The larger portion of it is highly dissected, consisting of knife-edge ridges and narrow valleys with very little level land. This type of rough broken land includes the great canyons of the island, which attain a maximum depth of nearly 4,000 feet with precipitous walls and short deeply entrenched tributaries. The materials are for the most part unconsolidated or weakly consolidated and erode rapidly. There is therefore very little development of a true soil profile or of weathered material in the area. Such small level areas as there are on the high uplands are wet and generally have light-gray soils. Associated with the trees and on the borders of the swamps are ferns of various species and shrubs, forming dense cover in the moderately wet situations. The lower dissected areas on the westward-facing slopes of the island differ in the character of the vegetation. The lands are largely forested with the wiliwili (*Erythrina monosperma*), with some kukui at the lower elevations. Koa occurs in scattered areas, but the better trees have been cut for lumber.

On Oahu, rough broken land includes the Waiane and Koolau mountain ranges which form perhaps 50 percent of the area of the island. These mountain ranges are highly dissected. Steep cliffs like Nuuanu Pali occur on the windward side of the ranges and on the leeward side of the Waiane range. The soils as a rule are shallow, owing to extreme erosion. In places there is a shallow soil, usually grayish brown in color on the surface and yellow or yellowish brown below. Wherever there are level areas the soil material is generally gray clay with yellowish clay subsoil. Vegetation consists of rain forest, for the most part, with moss and lichens on cliffs and steep slopes. Rainfall varies from 60 to 250 inches. A variation of the rough broken land occurs on the borders of the mountain ranges and consists of hilly or rough, badly eroded areas with small undulating or rolling areas of land suited to pasture. These lands have been mostly denuded of trees although a few shrubs persist. On the more gentle slopes and rolling lands the soil consists chiefly of dark grayish-brown granular clay loam or silty clay loam over a brown or reddish-brown friable silty clay subsoil. The rainfall varies from 40 to 70 inches. Part of the land has formerly been planted to pineapples, but much has been abandoned because of erosion. As protected watersheds, these lands have great value in the conservation of the water supplies of the island.

On Molokai there are two general types of rough broken land. One area in the northeastern part of the island occupies the cool, wet mountain lands. Rainfall is probably over 100 inches and well distributed throughout the year. Native vegetation is of the ohia-treefern association including small ferns and sedges. The ohia is usually dwarfed in appearance. This land is highly dissected with small, relatively gently sloping areas between gulches. The soils are of varying degrees of age and drainage. They vary from dark-brown, peaty, saturated, organic soils over gray or bluish-gray clayey inorganic material, which grades to rock at a shallow depth, to yellow, inorganic, shallow silty clay on steeper slopes. No one soil is characteristic of the entire area. The land is correctly used as forest and watershed reserves. Another type of rough broken land occurs in areas on both ends of the island. Erosion has dissected much of the land, leaving a surface largely devoid of soil. There is a wide range of climatic conditions, from dry lowlands to the wetter cooler highlands. Vegetation varies with the climatic conditions. The land is very rough and stony, and the little unconsolidated material present is largely young material. Land use is confined to grazing or forestry.

On both Lanai and Kahoolawe, rough broken land entirely surrounds plateau lands forming the dissected escarpments which in most places descend directly to the sea. Most of the land is subhumid to semiarid. It is mostly pasture; a small area on Lanai is forest land, and another small area is essentially waste land.

On Maui much of the rough broken land is similar to that on Kauai and Oahu. Included with the area on west Maui are small mountain bogs like that on Mount Waialae on Kauai.

Lava Beds

The area mapped as lava beds includes the lands on Hawaii and Maui covered by recent lava flows of both pahoehoe and aa types. The flows are all geologically

recent, some having occurred within the past 10 years. There is little or no accumulation of weathered materials. Much of the land is bare; elsewhere small shrubs and trees and tufts of grass have found foothold in crevasses or small areas of loose material. These lands have little or no agricultural value. The consolidated lava flows on the island of Maui occupy the extreme east end of the island. Like the lava beds on Hawaii, they are essentially bare of vegetation and of no present agricultural value.

Volcanic Cinders and Ash

Volcanic cinders and ash include all loose volcanic detritus nearly bare of vegetation in which but little weathering and soil development have taken place. The areas are confined to the islands of Hawaii and Maui. These materials on Hawaii are chiefly associated with Mauna Kea and Kilauea. The materials around Kilauea show definite stratification in places. These loose volcanic materials are, for the most part, at high altitudes where the climate is cool, with temperatures ranging down to freezing during the winter months. On Mauna Kea the land is covered with snow a considerable part of the year and frost is of common occurrence. The annual rainfall ranges from 80 to 100 inches. While much of the land is bare, the older portions, where the climate is less severe, support some grass, treeferns, and a scattering of ohia trees. On Maui the unconsolidated volcanic deposits are chiefly cinders around Mount Haleakala. The lands are largely bare and the climate is relatively severe, with frosts during the winter months and snow at the higher altitudes.

These loose, volcanic materials weather rapidly to form soils and at the lower elevations soon support some vegetation, part of which is of economic value.

A Glossary of Special Terms Used in the Soils Yearbook[1]

A HORIZON—See Horizon, soil.

ABC SOIL—A soil with a completely differentiated profile, including an A, a B, and a C horizon. (See Profile; Horizon.)

AC SOIL—A soil having an incomplete profile with only A and C horizons. A soil having no clearly developed B horizon. (See Profile; Horizon.)

ACID SOIL—A soil giving an acid reaction (precisely, below pH 7.0; practically, below pH 6.6) throughout most or all of the portion occupied by roots. More technically, a soil having a preponderance of hydrogen ions over hydroxylions in the soil solution. Indicator dyes (e. g., litmus) may be used for its determination. (See pH; Reaction, soil.)

AGGREGATE (of soil)—A single mass or cluster of soil consisting of many soil particles held together, such as a clod, prism, crumb, or granule.

AGRICULTURAL LAND—See Land.

AGRICULTURAL PRODUCTION—Production from crop or livestock enterprises on farms.

AGROLOGY—See Pedology.

AGRONOMY—See Pedology.

ALKALI SOIL—A soil containing alkali salts, usually sodium carbonate (with a pH value of 8.5 and higher). The term is frequently used loosely to include both alkali soil and saline soil as here defined. Where applied to saline soil the expression "white alkali" is used in some localities, and the expression "black alkali" is used for alkali soil as here defined, with or without the presence of neutral salts. (See pH; Saline soil.)

ALKALINE SOIL—Any soil that is alkaline in reaction. (Precisely, above pH 7.0; practically, above pH 7.3.) (See pH; Reaction, soil.)

ALLUVIAL SOILS—Azonal group of soils, developed from transported and relatively recently deposited material (alluvium) characterized by a weak modification (or none) of the original material by soil-forming processes. (See Alluvium; Azonal soils.)

ALLUVIUM—Fine material, such as sand, mud, or other sediments deposited on land by streams.

ALPINE (Mountain) MEADOW SOILS—Intrazonal group of dark-colored soils of the open or sparsely timbered and usually rather wet meadows found on high altitudes near and above the timber line. (See Intrazonal soil.)

AMMONIFICATION—Formation of ammonium compounds, or ammonia, as in soils, by soil organisms.

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[1] This glossary is not intended to be a dictionary of all terms used in soil science and related disciplines. It is by no means complete; it omits entirely the soil series names, and makes no attempt to include the technical terms used in the more specialized phases of soil physics, soil chemistry, and soil microbiology. In many instances explanations have been given rather than strict definitions, especially where terms have been used previously in more than one sense and where preciseness of definition would lead to extreme technicality. Competent authorities are not entirely agreed on the definition of some of the terms, and, although an attempt has been made to reflect the most commonly accepted ideas of the day, some almost arbitrary selection has been necessary. The definitions and explanations have been checked by a few leading soil scientists in the United States and further comments will be welcome. Terms that are new or that are used in a relatively new sense are marked with an asterisk (*). A further explanation of many of these will be found in the text of the book.

ANION—An ion carrying a negative charge of electricity. (See Ion.)
ARABLE LAND—See Land.
ARID CLIMATE—See Climate.
ASH—The nonvolatile residue resulting from the complete ignition (burning) of organic matter.
ASSOCIATION, SOIL—A group of soils, with or without common characteristics, geographically associated in an individual pattern. (An association may include one or more catenas. If the individual members of the association are not separable on a map of the scale employed, the association is considered a complex.) (See Catena; Complex.)
AZONAL SOILS—Any group of soils without well-developed profile characteristics, owing to their youth or conditions of parent material or relief, that prevent the development of normal soil-profile characteristics. In the United States these groups include the following: Alluvial soils, Lithosols (skeletal soils), and some dry sands. (See Alluvial soils; Dry sands; Lithosols; Profile.)

B HORIZON—See Horizon, soil.
BADLAND—See Land.
BASE MAP—A map having sufficient points of reference, such as State, county, or township lines, and other selected physical and cultural features, to allow the plotting of other special data. The base map for a detailed soil map shows political subdivisions, permanent physical features such as streams, shore lines, and mountains, and such cultural features as houses and roads, necessary for convenience in plotting the soil data. (See Soil map.)
BASIN LISTING—A method of tillage which creates small basins by damming lister furrows at regular intervals of approximately 4 to 20 feet. This facilitates retention, penetration, and uniform distribution of moisture and retards erosion on sloping lands.
BC SOIL—A soil with a profile having no A horizon. (Presumably the A horizon has been removed by erosion in most instances.) (See Horizon; Profile.)
BEDROCK—The solid rock underlying soils and other superficial formations.
BOG SOILS—An intrazonal group of soils with a muck or peaty surface soil underlain by peat, developed under swamp or marsh types of vegetation, mostly in a humid or subhumid climate. (See Intrazonal; Muck; Peat.)
BRECCIA—A fragmental rock with angular components as distinguished from conglomerate with water-worn components. There are friction or fault breccias, talus breccias, and erupted breccias.
BROWN FOREST SOILS—An intrazonal group of soils with very dark brown surface horizons, relatively rich in humus (mull) grading through lighter colored soil into the parent material, and characterized by slightly acid reaction, little or no illuviation of iron and alumina, and a moderately high content of calcium in the soil colloids. Developed under the deciduous forest in temperate humid regions from parent material relatively rich in bases. (See Colloid, soil; Eluviation; Horizon; Humus; Intrazonal; Parent material.)
*BROWN PODZOLIC SOILS—A zonal group of soils with a thin mat of partly decayed leaves over very thin dark grayish-brown humus-mineral soil and a trace of pale-gray leached A_2 horizon over a brown or yellowish-brown B horizon heavier in texture than the surface soil; developed under deciduous or mixed deciduous and coniferous forest in temperate or cool-temperate humid regions. (See Horizon; Zonal.)
BROWN SOILS—A zonal group of soils having a brown surface horizon which grades below into lighter colored soil and finally into a layer of carbonate accumulation; developed under short grasses, bunch grasses, and shrubs in a temperate to cool, semiarid climate. (See Carbonate accumulation; Horizon; Zonal.)

C HORIZON—See Horizon, soil.
CALCAREOUS SOIL—Soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly to the naked eye when treated with hydrochloric acid. Soil alkaline in reaction, owing to the presence of free calcium carbonate. (See Reaction, soil.)
CALCIFICATION—A general term used for that process or those processes of soil formation in which the surface soil is kept supplied sufficiently with calcium to saturate the soil colloids to a high degree with exchangeable calcium and thus render them relatively immobile and nearly neutral in reaction. The

process is best expressed in Chernozem and other soils having a horizon of carbonate accumulation. (See Carbonate accumulation; Chernozem soils; Colloid, soil; Exchange; Horizon; Reaction, soil.)

CALICHE—A more or less cemented deposit of calcium carbonate or of mixed calcium and magnesium carbonates, characteristic of soils of warm or hot desert and semiarid regions.

*CALOMORPHIC SOILS—Suborder of intrazonal soils owing their chief characteristics to the high content of calcium available to plants (frequently, but not always, in the form of soft calcium carbonate) in the parent material, such as Brown Forest and Rendzina soils. (See Brown Forest soils; Intrazonal; Parent material; Rendzina soils; Suborder.)

CARBON-NITROGEN RATIO—The relative proportion, by weight, of organic carbon to nitrogen in a soil. The number obtained by dividing the percentage of organic carbon in a soil by the percentage of nitrogen.

CARBONATE ACCUMULATION, SOIL HORIZON OF— A developed soil horizon, beneath the surface, containing more calcium (or magnesium and calcium) carbonate than the soil above it or the soil material below it. Characteristic of the Pedocal soils of Marbut's classification. (See Horizon; Pedocal.)

CATEGORY (soil classification)—Any one of the subdivisions of the system of classification in which soils are arranged on the basis of their characteristics. Beginning with the lowest category, soil type, soils are classified on the basis of progressively fewer characteristics into groups of progressively higher or more inclusive categories, namely, series, family, great soil group, suborder, and order. (See Family, soil; Great soil group; Order; Series; Suborder.)

CATENA, SOIL—A group of soils within one zonal region developed from similar parent material but differing in characteristics of the solum owing to differences in relief or drainage. From the Latin for chain. (See Parent material; Solum.)

CATION—An ion carrying a positive charge of electricity. (See Ion.)

CHERNOZEM SOILS—A zonal group of soils having a deep, dark-colored to nearly black surface horizon, rich in organic matter, which grades below into lighter colored soil and finally into a layer of lime accumulation; developed under tall and mixed grasses in a temperate to cool subhumid climate. From the Russian for black earth. Sometimes spelled Tschernosem, Tschernosiom. (See Carbonate accumulation; Horizon; Zonal soil.)

CHERT—An amorphous (without definite structure) form of silica (SiO_2) very closely allied to flint and characterized by a splintery fracture.

CHESTNUT SOILS—A zonal group of soils having a dark-brown surface horizon which grades below into lighter colored soil and finally into a horizon of lime accumulation; developed under mixed tall and short grasses in a temperate to cool and subhumid to semiarid climate. They occur on the arid side of Chernozem soils, into which they grade. (See Carbonate accumulation; Chernozem soils; Horizon; Zonal.)

*CHISEL—Any machine carrying one or more soil-penetrating points, with sufficient weight to force the points into the soil to a depth of 12 to 18 inches, so that they may be drawn along at that depth to loosen the subsoil. (See Subsoil.)

CLAY—The small mineral soil grains, less than 0.002 mm in diameter. (Formerly included the grains less than 0.005 mm in diameter.)

CLAYPAN—A dense and heavy soil horizon underlying the upper part of the soil; hard when dry and plastic or stiff when wet; presumably formed in part by the accumulation of clay brought in from the horizons above by percolating water. Common in many of the Planosols. (See Clay; Horizon; Planosol.)

CLIMATE:

Arid—A dry climate characteristic of desert and semidesert regions where precipitation effectiveness is such that only a sparse vegetation of desert plants prevails. The limits of precipitation vary considerably according to temperature conditions, with an upper limit for cool regions of 10 inches or less and for tropical regions of as much as 15 or 20 inches. (The Thornthwaite precipitation-effectiveness (P–E) index ranges between 0 and 16.) (See Precipitation effectiveness.)

Continental—A general term for the climate typical of great land masses, characterized by a great range of temperature and occurring in such parts of a continent as are not affected materially by nearness to the sea or other modifying influences.

Humid—Generally, a climate with sufficient precipitation to support a forest vegetation, although there are exceptions. The lower limit of precipitation in cool regions may be as little as 20 inches, whereas in hot regions it may be as much as 60 inches. The Thornthwaite precipitation-effectiveness index ranges between 64 and 128. The term "humid" also applies to atmospheric conditions. In this sense a humid climate is one in which the average relative humidity, as measured by the hygrometer, is very high. (See Precipitation effectiveness.)

Mediterranean—A general term used in reference to warm-temperate climates, relatively dry in the warm season and relatively moist in the cool season.

Oceanic—A general term for a climate modified by the tempering effect of ocean water, such that temperatures do not reach great extremes in either direction.

Semiarid—Climate characteristic of the regions intermediate between the true deserts and subhumid areas under which precipitation effectiveness is such that a vegetation of scattered short grass, bunch grass, or shrubs prevails. The upper limit of average annual precipitation in the cool semiarid regions is as low as 15 inches, whereas in tropical regions it is as high as 45 or possibly 50 inches. The Thornthwaite precipitation-effectiveness (P–E) index ranges between 16 and 32. (See Precipitation effectiveness.)

Subhumid—A climate intermediate between semiarid and humid, with sufficient precipitation to support a moderate to dense growth of tall and short grasses but in most instances insufficient to support a dense deciduous forest. Some subhumid areas, where the rainfall comes mostly during the growing season, have scattered deciduous trees with grass vegetation between. The upper limit of rainfall in subhumid climates may be as low as 20 inches in cool regions and as high as 60 inches in hot areas. Thornthwaite precipitation-effectiveness indexes are 32 to 48 for the dry subhumid and 48 to 64 for the moist subhumid. (See Precipitation effectiveness.)

Wet—The climate in which precipitation effectiveness is such that rain-forest vegetation prevails. The Thornthwaite precipitation-effectiveness index is above 128. (See Precipitation effectiveness.)

Wet-dry—The term "wet-dry" is applied to climate to indicate alternating wet and dry seasons, such as a wet summer and a dry winter, or the reverse. Some consider the climatic condition in the trade-wind belt, where daily showers are interspersed with dry sunny weather, to be wet-dry. The term is used more commonly, however, to apply to alternating wet and dry seasons.

COLLOID, SOIL—The term "colloid" is used in reference to matter, both inorganic and organic, having very small particle size and a correspondingly high surface area per unit of mass. Individual soil colloid particles are generally submicroscopic, or nearly so, but may be aggregated so that internal surface plays an important part. Furthermore, soil colloids differ from noncolloidal soil material in other ways than particle size. Formerly it was thought that the colloidal particles are not crystalline; now it is known that many mineral colloids exhibit crystalline structure when subjected to X-ray examination. Under certain conditions soil colloids form a more or less stable suspension or dispersion in water (colloidal solution) which is distinguished from true solution in that all particles have not dispersed to the molecular state. Colloids do not diffuse readily or pass through many animal or vegetable membranes. From the Greek for glue.

COLLUVIUM—Heterogeneous deposits of rock fragments and soil material accumulated at the base of comparatively steep slopes through the influence of gravity, including creep and local wash.

COMPLEX, SOIL—A soil association composed of such an intimate mixture of areas of soil series, types, or phases that these cannot be indicated separately upon maps of the scale used so that the association is mapped as a unit. (See Association, soil; Series, soil; Phase, soil; Type, soil.)

CONCRETIONS—Local concentrations of certain chemical compounds, such as calcium carbonate or compounds of iron, that form hard grains or nodules of mixed composition and of various sizes, shapes, and coloring.

CONSISTENCE, SOIL—The relative mutual attraction of the particles in the whole soil mass or their resistance to separation or deformation (as evidenced in cohesion and plasticity). Consistence is described by such general terms as loose or open; slightly, moderately, or very compact; mellow; friable; crumbly; plastic; sticky; soft; firm; hard; and cemented.

Consolidated (soil material)—Made solid, by cementation or other processes, from a previous fluid or loosely aggregated condition.

Continental climate—See Climate.

Contour furrows—Furrows plowed at right angles to the direction of slope, at the same level throughout and ordinarily at comparatively close intervals. They, together with the ridges produced by making the furrows, intercept and retain run-off water, thereby facilitating erosion control and moisture distribution, penetration, and retention.

Cropland—See Land.

Crust—A brittle layer of hard soil formed on the surface of many soils when dry.

Crust, desert—A hardpan of calcium carbonate, gypsum, or other binding material exposed at the surface in desert regions by wind or water erosion. Some think that desert crusts form on the surface, but it is believed that more of them form in the soil and are exposed by subsequent erosion.

Crystalline rock—A general term including igneous and metamorphic rocks composed of minerals in crystalline form. (See Igneous rock; Metamorphic rock.)

Dealkalization—Removal of alkali from the soil, usually by leaching. Technically, replacement of monovalent metallic ions, such as sodium, by alkaline earth cations, such as calcium, or by hydrogen ions. (See Cation; Ion; Leaching.)

Decalcification—Removal of calcium carbonate from the soil by leaching. Technically, replacement of calcium ions by monovalent cations. (See Cation; Ion; Leaching.)

Deflocculate—To separate or break down soil aggregates of clay into their individual particles; e. g., the dispersion of the particles of a granulated colloid to form a clay which tends to run or puddle. (See Clay; Colloid.)

Degradation (of soils)—Change of one soil type to a more highly leached one; e. g., the podzolization of a soil originally developed under the calcification process, as in the formation of a Podzol from a Chernozem. Sometimes used incorrectly to denote a decrease of soil fertility. (See Calcification; Chernozem soils; Leaching; Podzolization; Podzol soils; Type, soil.)

Degraded Chernozem—A zonal group of soils having a very dark brown to black surface horizon underlain by a dark- to light-gray leached horizon which rests upon a brown horizon; developed in the region between Chernozem and podzolic soils, where the forest vegetation has encroached upon grassland. (See Chernozem soils; Horizon; Leaching; Podzolic soils; Zonal soil.)

Dendritic—Marked by a branching habit resembling that of a shrub or tree; usually said of river systems, various plants, and of the veins of leaves of many higher plants.

Denitrification—The reduction of nitrates to nitrites, ammonia, and free nitrogen, as in soil by soil organisms, particularly anaerobic organisms (those living or active in the absence of air or free oxygen), under certain conditions.

Desalinization—Removal of salts from soil, usually by leaching. (See Leaching.)

Desert soils—A zonal group of soils having a light-colored surface soil, usually underlain by calcareous material and frequently by a hardpan; developed under an extremely scant shrub vegetation in warm to cool arid climates. (See Hardpan; Zonal soil.)

Detritus—A heterogeneous mass of fragments of stone or earth.

Drift—Material of any sort deposited in one place after having been moved from another. Glacial drift includes glacial deposits, unstratified (till) and stratified glacial outwash materials.

Dry sands—An azonal group of soils consisting of well-drained sandy deposits in which no clearly expressed soil characteristics have developed. (See Azonal soil; Sand.)

Drumlin—An oval hill of glacial drift, normally compact and unstratified, usually with its longer axis parallel to the movement of the ice responsible for its deposition. (See Drift.)

Duff—A type of organic surface horizon of forested soils, consisting of matted peaty organic matter only slightly decomposed. (See Horizon.)

Ecology—The branch of biology which deals with the mutual relations between organisms and their environment.

Edaphic—A general term for soil influences or conditions.

Edaphology—A term sometimes used for soil science, particularly for those phases of the science dealing with the influences of soil upon vegetation. (See Pedology.)

Electrolyte—(1) Any conductor of the electric current in which chemical change accompanies the passage of the current and is proportional to the current passed. Usually electrolytes are solutions of substances in a liquid. (2) By extension of meaning, any substance which, when added to a solvent, forms such a conductor; e. g., salt which, when added to water, forms an electrolyte.

Eluviation—The movement of soil material from one place to another within the soil, in solution or in suspension, when there is an excess of rainfall over evaporation. Horizons that have lost material through eluviation are referred to as eluvial and those that have received material as illuvial. Eluviation may take place downward or sidewise according to the direction of water movement. As used, the term refers especially, but not exclusively, to the movement of colloids, whereas leaching refers to the complete removal of material in solution. (See Horizon; Leaching.)

Erosion (land)—The wearing away of the land surface by running water, wind, or other geological agents, including such processes as gravitational creep.

Normal—The erosion characteristic of the land surface in its natural environment, undisturbed by human activity, as under the protective cover of the native vegetation. This type of erosion is sometimes referred to as geological erosion. It includes (1) rock erosion, or erosion of rocks, consolidated or unconsolidated, on which there is little or no true soil, as in stream channels, high mountains, and badlands, and (2) normal soil erosion, or the erosion characteristic of the soil type in its natural environment under the native vegetation, undisturbed by human activity.

Accelerated—Erosion of the soil or rock over and above normal erosion brought about by changes in the natural cover or ground conditions, including changes due to human activity and those caused by lightning or rodent invasion.

(a) *Sheet*—Removal of a more or less uniform layer of material from the land surface. The effects are less conspicuous than those of other types of erosion that produce large channels. Frequently in sheet erosion the eroding surface consists of numerous very small rills.

(b) *Rill*—That type of accelerated erosion by water which produces small channels that can be obliterated by tillage.

(c) *Gully*—That type of accelerated erosion by water which produces channels larger than rills. Ordinarily, these erosion-produced channels carry water only during and immediately after rains, or following the melting of snow. Gullies are deeper than rills and are not obliterated by normal tillage.

Soil—Removal of soil material from the solum by wind or running water, including normal soil erosion and accelerated soil erosion. Sometimes used loosely in reference to accelerated erosion only.

Exchange—As a chemical term, a reaction between two substances involving an interchange of parts.

Family, soil—A category in soil classification between series and great soil group; a taxonomic group of soils having similar profiles, composed of one or more distinct soil series. (See Category; Great soil group; Profile; Series, soil.)

Ferruginous—Iron-bearing; usually refers to material of comparatively high iron oxide content.

Fertility (of soil)—The quality that enables a soil to provide the proper compounds, in the proper amounts and in the proper balance for the growth of specified plants, when other factors, such as light, temperature, and the physical condition of the soil, are favorable.

First bottom—The normal flood plain of a stream, part of which may be flooded only at infrequent intervals. (See Flood plain; Second bottom.)

Flocculate—To aggregate individual particles into small groups or granules; used especially with reference to clay and colloid behavior. (See Clay; Colloid, soil.)

FLOOD PLAIN—The nearly flat surface subject to overflow along stream courses.

FOOD, PLANT—The organic compounds, elaborated within the plant, which nourish its cells. (Sometimes used loosely as an equivalent of plant nutrient.)

FOREST LAND—See Land.

FORMULA WEIGHT—The formula weights of compounds are the sums of the atomic weights represented in the formulas. The formula weights of Al_2O_3, H_2SO_4, and SiO_2 are therefore, respectively, $(2\times27)+(3\times16)=102$, $(2\times1)+32+(4\times16)=98$, and $28.1+(2\times16)=60.1$.

FREE—(As of silica, ferric oxide, etc.) A condition of a substance occurring in a mixture, where it is not chemically combined with other components of the mixture. Usually applied to iron oxide, alumina, and silica existing as such in contrast to the combined forms; e. g., SiO_2 is free silica, whereas kaolin—$Al_2O_3.2SiO_2.2H_2O$—contains combined silica.

FRIABLE—Easily crumbled in the fingers; nonplastic.

GENESIS, SOIL—Mode of origin of the soil, referring particularly to the processes responsible for the development of the solum from the unconsolidated parent material. (See Parent material; Solum.)

GENETIC—Pertaining to genesis or beginning.

GEOLOGICAL EROSION—See Erosion.

GLACIAL SOIL MATERIAL—Parent material of soil that has been moved and redeposited by glacial activity. (See Parent material.)

GLAUCONITE—An amorphous (without definite structure) silicate of iron and potassium. Considerable aluminum may be present also.

*GLEIZATION—A general term for the process of soil formation leading to the development, under the influence of excessive moistening, of a glei (gley) horizon in the lower part of the solum. A soil horizon in which the material ordinarily is bluish gray or olive gray, more or less sticky, compact, and often structureless, is called a glei horizon and is developed under the influence of excessive moistening. The process is important in the development of the Wiesenböden, Bog, and Half Bog soils. (See Bog soils; Half Bog soils; Horizon, soil; Solum; Wiesenböden.)

GRAY-BROWN PODZOLIC SOILS—A zonal group of soils having a comparatively thin organic covering and organic-mineral layers over a grayish-brown leached layer which rests upon an illuvial brown horizon; developed under deciduous forest in a temperate moist climate. (See Horizon, soil; Leaching; Zonal soil.)

GRAZING LAND—See Land.

GREAT SOIL GROUP (soil classification)—A group of soils having common internal soil characteristics; includes one or more families of soils. Among the zonal soils, each great soil group includes the soils having common internal characteristics developed through the influence of environmental forces of broad geographic significance, especially vegetation and climate; among the intrazonal soils, each great soil group includes the soils having common internal characteristics developed through the influence of environmental forces of both broad and local significance; among the azonal soils each great soil group includes similar soils that are without developed characteristics, owing to the influence of some local condition of parent material or relief. (See Azonal soil; Family, soil; Intrazonal soil; Parent material; Zonal soil.)

GREEN-MANURE CROP—Any crop grown and plowed under for the purpose of improving the soil, especially by the addition of organic matter.

*GROUND-WATER LATERITE SOILS—An intrazonal group of soils with bleached A horizons containing some concretions and more or less thick, cellular hardpans composed largely of iron and aluminum compounds; and with an alternating high and low water table. Found under warm-temperate to tropical climates. (See Concretions; Hardpan; Horizon, soil; Intrazonal soil; Water table.)

GROUND-WATER PODZOL SOILS—An intrazonal group of soils, developed from imperfectly drained sandy deposits in humid regions, having a thin organic layer over a light-gray sandy leached layer which rests upon a dark-brown B horizon irregularly cemented with iron or organic compounds, or both. The B horizon is called ortstein when cemented into a massive hardpan, and orterde where slightly and irregularly cemented. (See Hardpan; Horizon, soil; Intrazonal soil; Leaching; Orterde; Ortstein.)

GULLY EROSION—See EROSION.

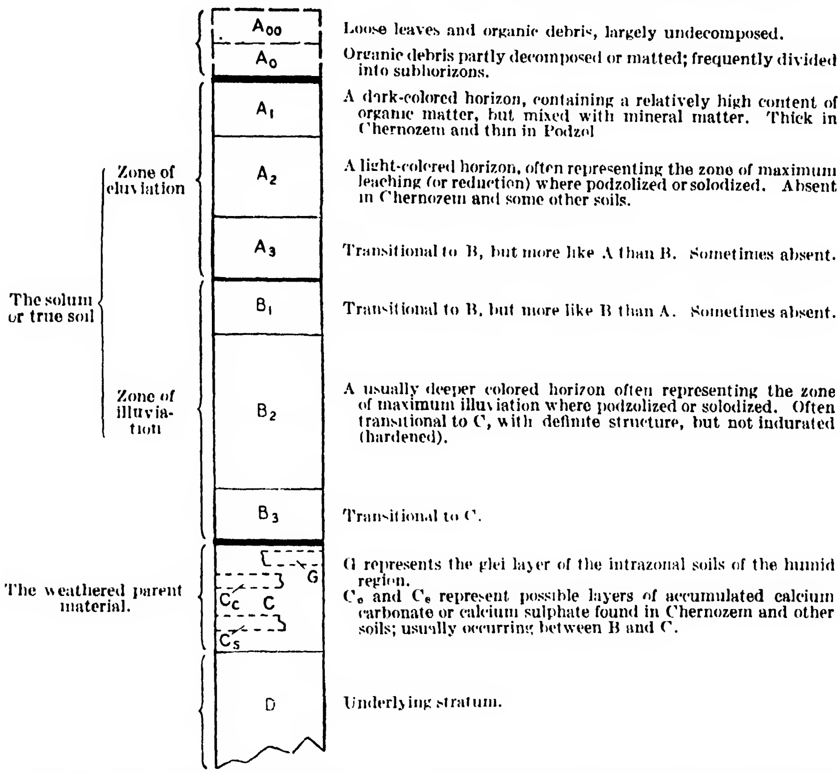
Half Bog soils—An intrazonal group of soils with mucky or peaty surface soil underlain by gray mineral soil; developed largely under swamp-forest types of vegetation, mostly in a humid or subhumid climate. (See Intrazonal soil.)

***Halomorphic soils**—A suborder of intrazonal soils, the properties of which are determined by the presence of neutral or alkali salts, or both. Halo is from the Greek for salt. (See Intrazonal soil; Suborder.)

Halophytic vegetation—Salt-loving or salt-tolerant vegetation, usually having fleshy leaves or thorns and resembling desert vegetation. Halo is from the Greek for salt.

Hardpan—An indurated (hardened) or cemented soil horizon. The soil may have any texture and is compacted or cemented by iron oxide, organic material, silica, calcium carbonate, or other substances. (See Horizon, soil; also Desert, Ground-Water Laterite, Ground-Water Podzol, and Planosol soils.)

Horizon, soil—A layer of soil approximately parallel to the land surface with more or less well-defined characteristics that have been produced through the operation of soil-building processes. The relative positions of the several soil horizons in the soil profile and their nomenclature are shown below:



Important subdivisions of the main horizons are conveniently indicated by extra numerals, thus: A_{21} and A_{22} represent subhorizons within A_2. (See Calcium carbonate accumulation; Chernozem soils; Eluviation; Gleization; Intrazonal soil; Parent material; Podzolized; Podzol soils; Profile; Solodized; Solum.)

Humid climate—See Climate.

Humus—The well-decomposed, more or less stable part of the organic matter of the soil.

Igneous rock—A rock produced through the cooling of melted mineral material.

Illuviation—See Eluviation.

Immature soil—A young or imperfectly developed soil.

Inherited characteristic (of soils)—Any characteristic of soil that is due directly to the nature of the parent material as contrasted to those partly or wholly due to the processes of soil formation. Example, the red color of a soil is said to be inherited if it is due entirely to the fact that the parent material is red.

Intrazonal soil—Any of the great groups of soils with more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief, parent material, or age over the normal effect of the climate and vegetation. Each group of these soils may be found associated with two or more of the zonal groups. In the United States the groups included are as follows (the terms are defined in this glossary): Brown Forest soil, Rendzina, Bog, Half Bog, Wiesenböden, Alpine Meadow, Ground-Water Podzol, Ground-Water Laterite, Planosol, Solonchak, Solonetz, and Soloth. (See Great soil group; Parent material; Zonal soil.)

Ion—An electrically charged element or group of elements in an electrolyte. More broadly, an electrically charged particle. (See Electrolyte.)

Kame—A short irregular ridge, hill, or hillock of stratified glacial drift. Most kames are hilly and are interspersed with depressions sometimes known as "kettles," having no surface drainage. (See Drift.)

Lacustrine deposits—Materials deposited by lake waters.

Land—The total natural and cultural environment within which production must take place. Its attributes include climate, surface configuration, soil, water supply, subsurface conditions, etc., together with its location with respect to centers of commerce and population. It should not be used as synonymous with soil or in the sense of the earth's surface only.

Agricultural—Land in farms regularly used for agricultural production. The term includes all the land devoted to crop or livestock enterprises; i. e., the farmstead, lanes, drainage and irrigation ditches, water supply, cropland, and grazing land of every kind in farms. It should not be used as synonymous with land in farms, cropland, pasture land, land suitable for crops, or land suitable for farming. The term "nonagricultural land" should not be used in the sense of land not suited to crops; such terms as "nonplowable," "nonarable," "land not in farms," and "land unsuited to crops," to suit the case, are preferable.

Arable—Land which, in its present condition, is physically capable, without further substantial improvement, of producing crops requiring tillage.

Badland—Nearly or partly barren, rough, broken land strongly dissected by streams; most common in semiarid and arid regions, where streams have entrenched themselves in soft geological materials, such as clays, soft shales, sandstones, and limestones.

Cropland—Land regularly used for crops, except forest crops. Cropland includes rotation pasture, cultivated summer fallow, or other land ordinarily used for crops but temporarily idle.

Forest—Land not in farms, bearing a stand of trees of any age or stature, including seedlings (reproduction), but of species attaining a minimum average height of 6 feet at maturity, or land from which such a stand has been removed, which is not now restocking, and on which no other use has been substituted. Forest on farms is called farm woodland or farm forest.

Grazing—Land regularly used for grazing, except cropland and rotation pasture. It is not confined to land suitable only for grazing.

Scabland—Land characterized by numerous outcrops of lava rock or scoria. This term, or "scabby land," is also applied locally to land having a large number of bare spots of Solonetz or solodized-Solonetz soils. (See Scoria; Solodized; Solonetz.)

Waste—Land essentially incapable of producing materials or services of value. This term should not be used to describe idle farm or forest land.

Landscape (as used in soil geography)—The sum total of the characteristics that distinguish a certain area on the earth's surface from other areas. These characteristics are the result not only of natural forces but of human occupancy and use of the land. Included among them are such features as soil types, vegetation, rock formations, hills, valleys, streams, cultivated fields,

roads, and buildings. All of these features together give the area its distinguishing pattern. The term may be used in a broad sense to include the complex pattern of an extensive area, such as the rural landscape, the mountain landscape, or the Chernozem landscape, or it may be restricted more closely by some factor or combination of factors, as the landscape of the Miami-Brookston soil association, the landscape of the Miami silt loam, or the landscape of the forested Plainfield sand.

LAND CLASSIFICATION—Classification of specific bodies of land according to their characteristics or to their capabilities for use. A natural land classification may be defined as one in which the natural land types are placed in categories according to their inherent characteristics. A land classification according to use capabilities may be defined as one in which bodies of land are classified (on the basis of physical or both physical and economic considerations) according to their capabilities for man's use, with sufficient detail of categorical definition and cartographic (mapping) expression to indicate those differences significant to men. (See Category.)

LAND RECLAMATION—Making land capable of more intensive use by changing its character, environment, or both through operations requiring collective effort. The clearing of stumps, brush, and stones from land, or simple techniques of erosion control that can be effected by the individual, are not to be included with reclamation.

LAND TYPE—Land uniformly possessed of particular distinguishing characteristics. A natural land type is land having a particular set of defined natural characteristics, principally of soil, climate, relief, stoniness, and native vegetation.

LAND USES, MAJOR RURAL—(1) Crop production (production of crops ordinarily harvested by man, except forest). (2) Grazing. (3) Forestry (production of repeated crops of forest products). (4) Recreation, including observation for educational purposes. (5) Wildlife preservation, propagation, or both. (6) Mineral extraction. (7) Protection (use of land to prevent injury to water supplies or to other more valuable land).

LAND-USE PATTERN—The areal design or arrangement of land uses, major and minor, and of operation units.

LAND-USE PLANNING—The development of plans for the uses of land that will, over a long period, best serve the general welfare, together with the formulation of ways and means of achieving such uses.

LATERITE SOILS—The zonal group of soils having very thin organic and organic-mineral layers over reddish leached soil that rests upon highly weathered material, relatively rich in hydrous alumina or iron oxide, or both, and poor in silica; usually deep-red in color. Laterite soils are developed under the tropical forest in a hot, moist, or wet-dry climate with moderate to high rainfall. (This definition is somewhat broader than some authorities might care to accept. The term is sometimes restricted to the highly weathered material with definite reticulate mottling as first described in India.) From the Latin for brick. (See Leaching; Reticulate mottling; Zonal soil.)

LATERIZATION (Lateritization)—The characteristic process which tends toward the production of Laterites and lateritic soils. Essentially it is the process of the silica removal with consequent increase in the alumina and iron oxide content and decrease in base-exchange capacity of the soil. (See Exchange; Laterite soils.)

LEACHING—Removal of materials in solution.

LIME—Strictly, calcium oxide (CaO), but, as commonly used in agricultural terminology, calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$) are included. Agricultural lime refers to any of these compounds, with or without magnesia, used as an amendment for acid soils.

LIMESTONE—A general name for rocks composed essentially of calcium carbonate. There are a great many different varieties varying in physical and chemical composition. Among these may be mentioned coralline limestone, composed of fragments of coral; dolomitic limestone, composed of a mixture of calcium and magnesium carbonates with minor impurities; and oolitic limestone, consisting of small, round grains resembling the roe of fish cemented together. Some dolomitic and oolitic limestones are composed of small roundish shells of minute animals.

*LITHOSOLS (skeletal soils)—An azonal group of soils having no clearly expressed soil morphology and consisting of a freshly and imperfectly weathered mass of

rock fragments; largely confined to steeply sloping land. Litho is from the Greek for rock. (See Azonal soil; Morphology, soil).

LOAM SOIL—See Texture.

MANGUM TERRACE—See Terrace.

MARL—An earthy crumbling deposit consisting chiefly of calcium carbonate mixed with clay or other impurities in varying proportions. It is used frequently as an amendment for soils deficient in lime.

MATURE SOIL—A soil with well-developed characteristics produced by the natural processes of soil formation, and in equilibrium with its environment.

MEDITERRANEAN CLIMATE—See Climate.

MELLOW SOIL—A soil that is easily worked or penetrated.

MESOPHYTIC VEGETATION—Vegetation that grows under medium conditions of atmospheric or soil moisture, as contrasted with xerophytic vegetation, able to withstand periodic or permanent conditions of low moisture; hydrophytic or aquatic vegetation; and halophytic vegetation, able to grow in soil of abnormally high salt content.

METAMORPHIC (OR METAMORPHOSED) ROCK—A rock the constitution of which has undergone pronounced alteration. Such changes are generally effected by the combined action of pressure, heat, and water, frequently resulting in a more compact and more highly crystalline condition of the rock. Gneiss, schist, and marble are common examples.

MICROCLIMATE—Local climatic conditions, brought about by the modification of general climatic conditions by local differences in elevation and exposure.

MICRORELIEF—Minor surface configurations, such as low mounds or shallow pits.

MINERAL SOIL—A general term used in reference to any soil composed chiefly of mineral matter.

MOBILE SOIL COLLOIDS—Soil colloids sufficiently dispersed that they may move in the soil with the percolating waters. (See Colloid, soil.)

MORPHOLOGY, SOIL—The physical constitution of the soil including the texture, structure, porosity, consistence, and color of the various soil horizons, their thickness, and their arrangement in the soil profile. (See Horizon, soil; Profile.)

MOTTLED (mottling)—Irregularly marked with spots of different colors.

MUCK—Fairly well decomposed organic soil material, relatively high in mineral content, dark in color, and accumulated under conditions of imperfect drainage.

MULL—A type of organic surface horizon of forested soils in which the organic matter is well decomposed and largely humus, granular in structure, relatively rich in bases, and medium acid to slightly alkaline in reaction. (See Horizon, soil; Humus; Reaction, soil.)

NEUTRAL SOIL—A soil that is not significantly acid or alkaline; strictly one having a pH of 7.0; practically, one having a pH between 6.6 and 7.3. (See Reaction, soil.)

NICHOLS TERRACE—See Terrace.

NITRIFICATION—Formation of nitrates from ammonia as in soils by soil organisms.

NITROGEN FIXATION—The conversion of atmospheric (free) nitrogen to nitrogen compounds. In soils, the assimilation of free nitrogen from the air by soil organisms (making the nitrogen eventually available to plants). Nitrogen-fixing organisms associated with plants such as the legumes are called symbiotic; those not definitely associated with plants are called nonsymbiotic.

NONCALCAREOUS—Free from calcium carbonate.

*NONCALCIC BROWN SOILS—The zonal group of soils with slightly acid light-pinkish or light reddish-brown A horizons over light reddish-brown or dull-red B horizons developed under mixed grass and forest vegetation in a subhumid wet-dry climate. (See Horizon, soil; Zonal soil.)

NORMAL SOIL—A soil having a profile in equilibrium with the two principal forces of the environment—native vegetation and climate—usually developed on the gently undulating (but not strictly level) upland, with good drainage, from any parent material, not of extreme texture or chemical composition, that has been in place long enough for biological forces to exert their full effect. (See Parent material; Profile.)

NUT STRUCTURE—See Structure, soil.

NUTRIENTS, PLANT—The elements taken in by the plant, essential to its growth, and used by it in the elaboration of its food and tissue. These include nitrogen, phosphorus, calcium, potassium, magnesium, sulphur, iron, manganese, copper, boron, zinc, and perhaps others obtained from the soil; and carbon, hydrogen, and oxygen, obtained largely from the air and water.

OCEANIC CLIMATE—See Climate.

*ORDER (soil classification)—The highest category in soil classification. The three orders are zonal, intrazonal, and azonal soils (defined elsewhere in the glossary) in the system of classification outlined in this Yearbook. (See Category.)

ORGANIC SOIL—A general term used in reference to any soil the solid part of which is predominantly organic matter.

ORTERDE—See Ortstein.

ORTSTEIN—Hard, irregularly cemented, dark-yellow to nearly black sandy material formed by soil-forming processes in the lower part of the solum. Similar material not firmly cemented is known as orterde. (See Solum.)

OXIDE—A compound of any element with oxygen alone.

OXIDATION—Any chemical change involving the addition of oxygen or its chemical equivalent. More technically, any chemical change involving an increase of positive or a decrease of negative valence.

PARENT MATERIAL—The unconsolidated mass from which the soil profile develops. (See Profile.)

PARENT ROCK—The rock from which parent materials of soils are formed. (See Parent materials.)

PEAT—Unconsolidated soil material consisting largely of undecomposed or slightly decomposed organic matter accumulated under conditions of excessive moisture.

PEDALFER—A term introduced by Marbut for a soil in which there has been a shifting of alumina and iron oxide downward in the soil profile but with no horizon of carbonate accumulation. Roughly equivalent to "soils of the humid regions." Derived from terms meaning soil, aluminum, iron. (See Carbonate accumulation; Horizon, soil; Profile.)

PEDOCAL—A term introduced by Marbut for a soil with a horizon of accumulated carbonates in the soil profile. Roughly equivalent to "soils of the arid and semiarid regions." Derived from terms meaning soil, calcium. (See Carbonate accumulation; Horizon, soil; Profile.)

PEDOGENIC PROCESSES—Processes of soil formation.

PEDOLOGIC (pedological)—Pertaining to pedology or soil science.

PEDOLOGIST—One versed in pedology; a soil scientist.

PEDOLOGY—The science that treats of soil; soil science. Pedo is from the Greek for ground or earth. The term is used commonly for the more fundamental aspects of soil science, whereas the term agrology is used sometimes for the applied phases of the subject. In the United States, the term "agronomy" is used frequently to cover the applied phases of both soil science and the several plant sciences dealing with crops. This use of agronomy is so broad as to be somewhat confusing, however, and more and more this term is being confined to the applied phases of the plant sciences dealing with crops. The term "edaphology" has been used by some as an approximate equivalent to soil science and by others to cover plant-soil relationships. Although it is not widely used, one of its derivatives, edaphic, is used by ecologists as a general term for soil influences or conditions. (See Ecology; Edaphology.)

PELITE—A general name for rocks composed of fine particles of clay or mud, such as clay and shale.

PENEPLAIN—A land surface reduced by erosion almost to base level so that most of it is approximately a plain. In physiography the term "peneplain" is applied to old land surfaces which were formerly reduced almost to base level and subsequently raised bodily to a higher level, and which may or may not have been again intersected by streams. Where intersected, the old peneplain surface is represented by remaining flat hilltops, and in many places it is possible to trace remains of several different peneplain levels. Pene is from the Latin for almost.

pH—A notation introduced by Sorensen to designate relatively weak acidity and alkalinity, such as is encountered in soils and biological systems. Tech-

nically, the common logarithm of the reciprocal of the hydrogen-ion concentration of a system. A pH of 7.0 indicates precise neutrality, higher values indicate alkalinity, and lower values acidity. (See Reaction, soil.)

PHASE, SOIL—That part of a soil unit or soil type having minor variations in characteristics used in soil classification from the characteristics normal for the type, although they may be of great practical importance. The variations are chiefly in such external characteristics as relief, stoniness, or accelerated erosion.

*PLANOSOL—An intrazonal group of soils with eluviated surface horizons underlain by B horizons more strongly illuviated, cemented, or compacted than associated normal soils, developed upon nearly flat upland surface under grass or forest vegetation in a humid or subhumid climate. (See Eluviation; Horizon, soil; Intrazonal soil.)

PLASTIC—Capable of being molded or modeled without rupture; not friable.

PLATY—See Structure, soil.

POCOSIN—A local term for a swamp, usually containing more or less peat, characteristic of southeastern United States.

PODZOL SOILS—A zonal group of soils having an organic mat and a very thin organic-mineral layer above a gray leached layer which rests upon an illuvial dark-brown horizon, developed under the coniferous or mixed forest, or under heath vegetation in a temperate to cold moist climate. Iron oxide and alumina, and sometimes organic matter, have been removed from the A and deposited in the B horizon. From the Russian for like, or near, ash. (See Eluviation; Horizon, soil; Leaching; Zonal soil.)

PODZOLIC SOILS—Soils that have been formed wholly or partly under the influence of the podzolization process.

PODZOLIZATION—A general term referring to that process (or those processes) by which soils are depleted of bases, become acid, and have developed eluvial A horizons (surface layers of removal) and illuvial B horizons (lower horizons of accumulation). Specifically the term refers to the process by which a Podzol is developed, including the more rapid removal of iron and alumina than of silica, from the surface horizons, but it is also used to include similar processes operative in the formation of certain other soils of humid regions. (See Eluviation; Horizon, soil; Podzol soils.)

POROSITY, SOIL—The degree to which the soil mass is permeated with pores or cavities. It is expressed as the percentage of the whole volume of the soil which is unoccupied by solid particles.

PRAIRIE SOILS—The zonal group of soils having a very dark brown or grayish-brown surface horizon, grading through brown soil to the lighter colored parent material at 2 to 5 feet, developed under tall grasses, in a temperate, relatively humid climate. The term has a restricted meaning in soil science and is not applied to all dark-colored soils of the treeless plains but only to those in which carbonates have not been concentrated in any part of the profile by the soil-forming processes. (See Horizon, soil; Profile; Zonal soil.)

PRECIPITATION-EFFECTIVENESS (P-E) INDEX—The sum of the 12 monthly quotients of precipitation divided by evaporation. (See Thornthwaite, *402a*, *402b*.)[2]

PRISMATIC—See Structure, soil.

PRODUCTIVITY (of soil)—The capability of a soil for producing a specified plant or sequence of plants under a specified system of management.

PROFILE, SOIL—A vertical section of the soil through all its horizons and extending into the parent material. (See Horizon, soil; Parent material.)

REACTION, SOIL—The degree of acidity or alkalinity of the soil mass expressed in pH values, or in words as follows:

	pH		pH
Extremely acid	Below 4.5	Neutral[3]	6.6–7.3
Very strongly acid	4.5–5.0	Mildly alkaline	7.4–8.0
Strongly acid	5.1–5.5	Strongly alkaline	8.1–9.0
Medium acid	5.6–6.0	Very strongly alkaline	9.1 and higher
Slightly acid	6.1–6.5		

[2] Italic numbers refer to Literature Cited, p. 1181.

[3] Strict neutrality is precisely pH 7.0. Very few actual soil samples have this value and those having pH values between 6.6 and 7.3 are considered, for all practical purposes, neutral. For more precise identification, those between 6.6 and 7.0 may be described as very slightly acid and those between 7.0 and 7.3 as very mildly alkaline.

*REDDISH BROWN SOILS—A zonal group of soils with a light-brown surface horizon of a slightly reddish cast, which grades into dull reddish-brown or red material heavier than the surface soil, thence into a horizon of whitish or pinkish lime accumulation. Developed under shrub and short-grass vegetation of warm-temperate to tropical regions of semiarid climate. (See Horizon, soil: Zonal soils.)

RED DESERT SOIL—A zonal group of soils having light reddish-brown friable soil over a reddish-brown or dull-red heavy horizon grading into an accumulation of carbonate of lime; found in warm-temperate and tropical deserts and characterized by more or less scant desert-shrub vegetation. (See Carbonate accumulation; Horizon, soil; Zonal soils.)

*REDDISH-BROWN LATERITIC SOILS—A zonal group of soils with dark reddish-brown granular surface soils, red friable clay B horizons, and red or reticulately mottled lateritic parent material; developed under humid tropical climate with wet-dry seasons and tropical forest vegetation. (See Horizon, soil; Lateritic soils; Parent material; Zonal soil.)

*REDDISH CHESTNUT SOILS—A zonal group of soils with dark-brown, tinted pinkish or reddish surface soils up to 2 feet thick over heavier reddish-brown soil over grayish or pinkish lime accumulation; developed under warm-temperate semiarid climate and mixed grass vegetation with some shrubs. Approximately equivalent to southern Chernozem. (See Chernozem soils, Zonal soil.)

*REDDISH PRAIRIE SOILS—A zonal group of soils with dark reddish-brown, slightly to medium acid surface soils grading through somewhat heavier reddish material to the parent material; developed under warm-temperate humid to subhumid climate and tall-grass vegetation. (See Parent material; Zonal soil.)

*RED PODZOLIC SOILS—A zonal group of soils having thin organic and organic-mineral layers over a yellowish-brown leached layer which rests upon an illuvial red horizon; developed under a deciduous or mixed forest in a warm-temperate moist climate. Equivalent to Red soils. (See Eluviation; Leaching; Horizon, soil; Zonal soil.)

REDUCTION—Any chemical change involving the removal of oxygen or its chemical equivalent. More technically, any chemical change involving a decrease of positive or an increase of negative valence.

REGIONAL PROFILE (soil)—A soil profile that owes its character largely to the effects of the climate and vegetation normal for the region in which it has formed. The mature normal soil characteristic of a given soil region. (See Profile.)

RELIEF—The elevations or inequalities of a land surface, considered collectively.

RENDZINA SOILS—An intrazonal group of soils, usually with brown or black friable surface horizons underlain by light-gray or yellowish calcareous material; developed under grass vegetation or mixed grasses and forest, in humid and semiarid regions from relatively soft, highly calcareous parent material. From a Polish peasant term for productive calcareous soils. (See Horizon, soil; Intrazonal soil; Parent material.)

RESIDUAL OR SEDENTARY MATERIAL—Soil material presumably developed from the same kind of rock as that on which it lies. The term "residual" is sometimes incorrectly applied to soils.

RETICULATE MOTTLING—A network of coarse streaks of different colors in soils or parent materials; applied especially to lateritic materials and Laterite. Sometimes called vermiculate mottling. (See Laterite soils; Parent material.)

RILL EROSION—See Erosion.

SALINE SOIL—A soil containing an excess of soluble salts, more than approximately 0.2 percent, not excessively alkaline, pH less than 8.5; approximately equivalent to Solonchak. (See Solonchak.)

SALT—The product, other than water, of the reaction of a base with an acid.

SAND—Small rock or mineral fragments having diameters ranging from 1 to 0.05 mm; coarse sand, 1 to 0.5; sand, 0.5 to 0.25; fine sand, 0.25 to 0.1; very fine sand, 0.1 to 0.05. The term "sand" is also applied to soils containing 90 percent or more of all grades of sand combined. Although usually made up chiefly of quartz, sands may be composed of any materials or mixtures of mineral or rock fragments.

SCABLAND—See Land.

SCORIA—A slaglike clinker deposit characteristic of burned-out coal beds, especially in the western Great Plains. The term "scoria" is also applied to slaglike lava deposits.

SECOND BOTTOM—The first terrace level of a stream valley lying above the flood plain, rarely or never flooded. (See First bottom; Flood plain.)

SEDIMENTARY ROCK—A rock composed of particles deposited from suspension in water. The chief groups of sedimentary rocks are (1) conglomerates (from gravels), (2) sandstones (from sands), (3) shales (from clays), and (4) limestones (from calcium carbonate deposits); but there are many intermediate types.

SEMIARID CLIMATE—See climate.

SERICITIC PHYLLITE—A phyllite containing a large proportion of the scaly variety of muscovite mica known as sericite.

SERIES, SOIL—A group of soils having genetic horizons similar as to differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and developed from a particular type of parent material. A series may include two or more soil types differing from one another in the texture of the surface soils. (See Horizon, soil; Parent material; Profile; Type, soil.)

SHEET EROSION—See Erosion.

SIEROZEM SOILS—A zonal group of soils having a brownish-gray surface horizon that grades through lighter colored material into a layer of carbonate accumulation and frequently into a hardpan layer, developed under mixed shrub vegetation in a temperate to cool arid climate. From the Russian for gray earth. (See Carbonate accumulation; Hardpan; Horizon, soil.)

SILICA-ALUMINA RATIO (in soils and colloids)—Since equal weights of substances are not equal in chemical value, in order to compare chemically the quantities of substances found by analyses of soils or of their colloids, it is customary to divide the actual weights (or the percentage amounts) of substances by their formula weight, in order to obtain the relative number of chemical units. These relative quantities may then be expressed as a ratio. If then, in a colloid, the quantities of silica and of alumina are found to be 30.90 and 32.58, then the silica-alumina ratio is—

$$\frac{\frac{30.90}{60.3}}{\frac{32.58}{102.2}}=1.61$$

This means that in this colloid there are 1.61 units of silica as compared with 1 of alumina. Usually, ratios of this sort are more useful in the study of soil colloids than of soils. This apparently irregular method of expression of the relative chemical units in soil colloids is due to the fact that these colloids are complex mixtures of a variety of compounds, and therefore the ordinary mode of expression of chemical composition by formulas is impossible.

SILICA-SESQUIOXIDE RATIO—If the analysis of a soil colloid shows the presence of 44.86 silica, 7.40 iron oxide, and 22.04 alumina, then the silica-sesquioxide ratio is found as follows:

$$\begin{aligned}44.86 \div 60.3 &= 0.7440\\ 7.40 \div 159.7 &= 0.0463\\ 22.04 \div 102.0 &= 0.2161\end{aligned}$$

The quotients represent the relative chemical unit quantities of these three substances in this colloid. If 0.744 is divided by the sum of 0.0463 and 0.2161, the quotient is 2.84, the silica-sesquioxide ratio. This means that for each unit of the alumina and iron oxide, taken together, there are 2.84 units of silica. The two oxides, alumina (Al_2O_3) and iron oxide (Fe_2O_3), are the only two oxides in soils, in any considerable quantity, in which the elements are present in the ratio of 2 to 3, or 1 to 1½; hence the term sesquioxide. (See Silica-alumina ratio.)

SILT—Small mineral soil grains the particles of which range in diameter from 0.05 to 0.002 mm (or 0.02–0.002 mm in the international system). (Formerly 0.05–0.005 mm.)

Skeletal soils—Equivalent to Lithosols.

Soil—The natural medium for the growth of land plants on the surface of the earth. A natural body on the surface of the earth in which plants grow, composed of organic and mineral materials.

Soil climate—Moisture and temperature conditions within the soil.

Soil map—A representation designed to portray the distribution of soil types, phases, and complexes as well as other selected cultural and physical features of the earth's surface necessary for convenience in its use.

Detailed—The boundaries of soil types and phases are plotted upon the base map from precisely located points and from observations made throughout their course in sufficient detail to indicate those differences of significance in the use of the land.

Reconnaissance—The boundaries between the soil types and phases are plotted from observations made at intervals.

Detailed-reconnaissance—A map having parts constructed according to the requirements of the detailed soil map and parts according to the less rigid requirements of the reconnaissance soil map. (See Complex; Phase; Type.)

Soil survey report—A written report accompanying a soil map describing the area surveyed, the characteristics and capabilities for use of the soil types and phases shown on the map, and the principal factors responsible for soil development. (See Phase; Type.)

Solodized soil—A soil that has been subjected to the processes responsible for the development of a Soloth and having at least some of the characteristics of a Soloth. (See Soloth soils.)

Solonchak soils—An intrazonal group of soils having a high concentration of soluble salts; usually light colored; without characteristic structural form; developed under salt-loving grass or shrub vegetation mostly in an arid, semiarid, or subhumid climate. From the Russian for salt. (See Intrazonal soil.)

Solonetz soils—An intrazonal group of soils having a variable surface horizon of friable soil underlain by dark hard soil, ordinarily with columnar structure; usually highly alkaline; developed under grass or shrub vegetation, mostly in a subhumid or semiarid climate. From the Russian for salt. (See Horizon, soil; Intrazonal soil; Structure, soil.)

Soloth soils—An intrazonal group of soils having a thin surface layer of brown friable soil above a gray leached horizon which rests upon a brown or dark-brown horizon; developed under shrubs, grasses, or mixed grasses and trees usually in a semiarid or subhumid climate. From the Russian for salt. Solodi or Solodee, plural forms, also are used. (See Horizon, soil; Intrazonal soil; Leaching.)

Solum—The upper part of the soil profile, above the parent material, in which the processes of soil formation are taking place. In mature soils this includes the A and B horizons, and the character of the material may be, and usually is, greatly unlike that of the parent material beneath. Living roots and life processes are largely confined to the solum. (See Horizon, soil; Parent material.)

Stratified—Composed of, or arranged in, strata or layers, as stratified alluvium. The term is applied to geological materials. Those layers in soils that are produced by the processes of soil formation are called horizons, while those inherited from the parent material are called strata.

Strip cropping—Strip cropping is a practice of growing ordinary farm crops in long strips of variable widths, across the line of slope, approximately on the contour, on which dense-growing crops are seeded in alternate strips with clean-tilled crops.

Structure, soil—The morphological aggregates in which the individual soil particles are arranged. The following are the principal types of soil structure:

Prismatic—Blocky structure with the vertical axis of the blocks longer than the horizontal, as in the B horizon of many Chestnut soils.

Nutlike—Blocky structure, angular, as in the B horizon of the Gray-Brown Podzolic soils, or rounded, as in the B horizon of many Chernozems.

Columnar—Prismatic with rounded tops, as in the B horizon of the solodized-Solonetz.

Platy—Thin horizontal plates, as in the A_2 horizons of the Podzol and the solodized-Solonetz.

Crumb—Generally soft, small, porous aggregates, irregular in shape, as in the A_1 horizons of many soils.

Granular—Hard or soft but firm small aggregates, angular or rounded, as in the A horizon of many Chernozems.

Fragmental—Hard or soft but firm irregular aggregates, angular or subangular, as in many young soils developed from silty or clayey alluvium.

**Phylliform*—Thin leaflike layers, less distinct and thinner than platy. Where this condition is confined to inherited layers, as in the C horizon of soils developed from thin-bedded sediments, the term laminated is used.

To indicate a lack of definite structure, the following terms are normally used:

Single grain—Each grain by itself, as in dune sand (structureless).

Massive—Large uniform masses of cohesive soil, sometimes with irregular cleavage, as in the C horizons of many heavy clay soils (structureless).

(See Aggregate; Alluvium; Chernozem soils; Gray-Brown Podzolic soils; Horizon, soil; Morphology; Solodized; Solonetz soils.)

SUBHUMID CLIMATE—See Climate.

*SUBORDER (soil classification)—The second highest category in soil classification, including the main groups of great soil groups. (See Category; Great soil groups.)

SUBSOIL—Roughly, that part of the solum below plow depth. (See Solum.)

SURFACE SOIL—That part of the upper soil of arable soils commonly stirred by tillage implements or an equivalent depth (5 to 8 inches) in nonarable soils.

SYMBIOTIC—See Nitrogen fixation.

TALUS—Fragments of rock and soil material collected at the foot of cliffs or steep slopes, chiefly as a result of gravitational forces.

TERRACE (for control of run-off, or soil erosion, or both)—A broad surface channel or embankment constructed across the sloping lands, on or approximately on contour lines, at specific intervals. The terrace intercepts surplus run-off, to retard it for infiltration or to direct the flow to an outlet at nonerosive velocity.

Types of terraces:

Absorptive—A ridge type of terrace used primarily for moisture conservation. It is adapted to low slopes and absorptive soils. A Mangum terrace is a broad-based ridge type, named for the man who first designed it.

Bench—A terrace approximately on the contour, having a steep or vertical drop to the slope below, and having a horizontal or gentle sloping part which is farmed. It is adapted to the steeper slopes.

Drainage—A broad channel-type terrace used primarily to conduct water from the field at a low velocity. It is adapted to less absorptive soil and regions of high rainfall. A Nichols terrace is a broad-channel type named after the man who first designed it.

TERRACE (geological)—A flat or undulating plain, commonly rather narrow and usually with a steep front, bordering a river, a lake, or the sea. Many streams are bordered by a series of terraces at different levels, indicating the flood plains at successive periods. Although many older terraces have become more or less hilly through dissection by streams, they are still regarded as terraces.

TEXTURE, SOIL—The relative proportion of the various size groups of individual soil grains.

Soil separates—The individual size groups of soil particles, such as sand, silt, and clay.

Soil class—Classes of soil based on the relative proportion of soil separates The principal classes, in increasing order of the content of the finer separates, are as follows: Sand, loamy sand, sandy loam, loam, silt loam, clay loam, and clay. These may be modified according to the relative size of the coarser particles to fine sand, loamy fine sand, fine sandy loam, very fine sandy loam, coarse sandy loam, gravelly sandy loam, gravelly loam, cobbly loam, sandy clay, stony clay, silty clay, stony loam, etc.

TILL (glacial)—A deposit of earth, sand, gravel, and boulders transported by glaciers. Till is unstratified.

TILL PLAIN—A level or undulating land surface covered by glacial till.

TILTH—The physical condition of a soil in respect to its fitness for the growth of a specified plant.

TOPSOIL—A general term applied to the surface portion of the soil, including the

average plow depth (surface soil) or the A horizon, where this is deeper than plow depth. It cannot be precisely defined as to depth or productivity except in reference to a particular soil type.

TRANSITIONAL SOIL—Soil that does not clearly belong to any important soil group or series with which it is associated, but has some properties of each.

TRANSPORTED SOIL MATERIALS—Parent materials of soils that have been moved from the place of their origin and redeposited during the weathering process itself or during some phase of that process, and which consist of, or are weathered from, unconsolidated formations.

TROCKENTORF—A peatlike deposit, relatively undecomposed, found on the surface of well-drained soils under forest cover, and composed of the remains of leaves and fragments of wood. From the German for dry turf.

TRUNCATED SOIL PROFILE—A soil profile that has had a part of the solum removed by accelerated erosion. (See Solum.)

TUFF (tufa)— A rock composed of the finer kinds of volcanic detritus, usually more or less stratified and in various states of consolidation. There are many varieties. Tufa applies to similar rocks, but more especially to a kind of porous rock formed as a deposit from springs or streams; usually applied to calcareous deposits (travertine) in the phrase, "calcareous tufa." (See Detritus.)

TUFFACEOUS—Of, pertaining to, or like tuff.

TUNDRA SOILS—A zonal group of soils having dark-brown highly organic layers over grayish horizons which rest on an ever-frozen substratum; developed under shrubs and mosses in cold, semiarid to humid climates, i. e., in Arctic regions. (See Horizon, soil; Zonal soil.)

TYPE, SOIL—A group of soils having genetic horizons similar as to differentiating characteristics, including texture and arrangement in the soil profile, and developed from a particular type of parent material. (See Horizon, soil; Parent material; Profile.)

UNCONSOLIDATED (soil material)—Soil material in a form of loose aggregation.

VARNISH, DESERT— A glossy coating of dark-colored compounds, probably composed largely of iron oxides, covering pebbles, stones, and large rock surfaces exposed in hot deserts.

VERTICAL ZONALITY OF SOILS— The distribution of different great soil groups on mountain slopes, each group occupying a definite climatic and vegetation zone. (See Great soil group.)

VESICULAR STRUCTURE—Soil structure characterized by round or egg-shaped cavities or vesicles.

WASTE LAND—See Land.

WATER TABLE—The upper limit of the part of the soil or underlying material wholly saturated with water.

WEATHERING—The physical and chemical disintegration and decomposition of rocks and minerals.

WET CLIMATE— See Climate.

WET-DRY CLIMATE—See Climate.

WIESENBÖDEN (Meadow soils)—An intrazonal group of soils with dark-brown or black soil high in organic matter grading at 6 to 30 inches into gray soil; developed under grasses and sedges, mostly in a humid or subhumid climate. (See Intrazonal soils.)

*YELLOW PODZOLIC SOILS—A zonal group of soils having thin organic and organic-mineral layers over a grayish-yellow leached layer which rests on a yellow horizon; developed under the coniferous or mixed forest in a warm-temperate moist climate. Equivalent to Yellow soils.

*YELLOWISH-BROWN LATERITIC SOILS—A zonal group of soils characterized by yellowish-brown friable and granular surface horizons high in clay content over yellow or reddish-yellow friable clay material overlying parent materials usually not strongly mottled. Developed under tropical forest in hot, humid to subhumid, wet-dry climate. (See Horizon, soil; Parent material; Zonal soil.)

XEROPHYTIC VEGETATION—Vegetation characteristic of the desert regions; thorny brush, cacti, shrubs, and small flowering annual and perennial plants.

Zonal soil—Any one of the great groups of soils having well-developed soil characteristics that reflect the influence of the active factors of soil genesis—climate and living organisms, chiefly vegetation. In the United States these groups include the following (defined elsewhere in this glossary): Tundra, Podzol, Brown Podzolic, Gray-Brown Podzolic, Red and Yellow Podzolic, Yellowish-Brown and Reddish-Brown Lateritic, Laterite, Prairie, Reddish Prairie, Noncalcic Brown, Degraded Chernozem, Chernozem, Chestnut, Reddish Chestnut, Brown, Reddish Brown, Sierozem, Desert, and Red Desert soils. (See Great soil groups.)

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